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THE CONCENTRATION OF CARBON DIOXIDE IN THE SOIL AIR UNDER VARIOUS CROPS AND IN FALLOW SOILS[1]

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The soil is a three-phase system, consisting of the solid, the liquid and the gaseous phases. In a given volume of soil in its natural condition, only a portion of the total volume is occupied by the soil particles. The remainder of the volume consists of interstitial spaces which are ordinarily filled with water and air. The amount of air in the soil depends upon the texture, the structure and the percentage of moisture. In a given soil the amount of air or free pore space is limited by the amount of water present.

The composition of the soil air varies from day to day as well as from one season to another. It differs from the atmosphere in that it usually contains a larger proportion of carbon dioxide and a smaller proportion of oxygen and nitrogen.

Carbon dioxide may be produced in the soil in a number of ways. Some investigators have claimed that it results mainly from the decomposition of organic matter by microorganisms. It is well established, however, that under certain conditions plant roots growing in the soil may produce a large proportion of the carbon dioxide in the soil air. Carbon dioxide may also be produced in the soil by chemical reaction, but the amount produced in this way is probably always small. The carbon dioxide produced in the soil may accumulate to a certain extent in the soil air, it may pass out into the atmosphere by diffusion or it may go into solution or be absorbed in the soil. Therefore, the percentage of carbon dioxide found in the soil air at a given time will be the resultant of the rate of production on the one hand, and the rate of escape or removal on the other. The rate of production of carbon dioxide in the soil depends upon a number of factors, such as the temperature, the moisture, the microbiological action, the soil, and the crop grown, if the soil is not fallowed. The rate of diffusion of carbon dioxide through a dry soil is directly related to the porosity (15) but the relations of moisture, temperature and structure to the rate of diffusion have not been so definitely shown. Thus, it is evident that the concentration of carbon dioxide in the soil air is a resultant of a great many factors and while it is not a measure of rate of production it may be expected to show wide differences in rate of production. Therefore, under a given set of conditions, and in a particular soil, the influence of seasonal conditions and kind of crop on rate of production of carbon dioxide may be reflected in the concentration of carbon dioxide in the soil air.

Considerable information has been obtained regarding the concentration of carbon dioxide in the soil air and the factors influencing it but few results are available showing the relative effects of different crops at least with the conditions of the experiment sufficiently well defined to permit of conclusions. The object of this investigation was to determine the con-

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centration of carbon dioxide in the soil air in fallow soils, and in the same soils under various crops and different cropping systems under field conditions.

HISTORICAL

Boussingault and Lewy (3) determined the concentration of carbon dioxide in the soil air under various crops and in forest and fallow soils. They found very little difference in the percentage of carbon dioxide in the soil air under such crops as alfalfa, artichokes, sugar beets, asparagus, and carrots. However, large differences were found in the concentration of carbon dioxide in the soil air of sands, clays and soils well supplied with organic matter.

Knop (7) determined the amount of carbon dioxide given off by corn plants, and found that smaller plants gave off less carbon dioxide than larger ones. A plant which weighed 170 grams and was 90 cm. high gave off an average of 314 milligrams of carbon dioxide per 24 hours.

Cauvet (4) determined the amount of carbon dioxide given off by the roots of a bean plant every four hours during the day, and once every 24 hours at night. It was found that less carbon dioxide was excreted during the night than during any single period of the day.

Wollny (19) studied the influence of shade or cover on the concentration of carbon dioxide in the soil air. The concentration at 25 cm. depth under grass was 0.1993 per cent, under a cover of straw 0.675 per cent and in bare soil 0.883 per cent. The influence of density of plant cover on the concentration of carbon dioxide in the soil air was studied in another experiment. Oats were planted in cylinders 10 cm. in diameter carrying 3, 6, 12 and 24 plants per cylinder. The average percentages obtained during June, July and August, were 0.497 per cent, 0.344 per cent, 0.231 per cent and 0.187 per cent for cylinders carrying 3, 6, 12 and 24 plants respectively.

Kossowitch (8) determined the amount of carbon dioxide given off by the roots of mustard in a study of the part played by plant roots in dissolving insoluble plant food constituents in soils. The plants were grown in zinc containers which held about 600 grams of soil. The soil in the containers, both planted and unplanted, was leached with a nutrient solution at the rate of 5 liters per 24 hours and the amount of carbon dioxide contained in the leachate determined. The determination of carbon dioxide began the 18th day after seeding and continued 75 days. The mustard was about 1 meter high and was in the blooming stage at the end of the period. The amount of carbon dioxide given off during the day was determined separately from that evolved during the night. The data presented show that the amount of carbon dioxide given off during the day was usually less than the amount given off during the night, and that the amount given off during both day and night gradually increased until the end of the period.

Stoklasa and Ernest (16), working with sugar beets, clover, wheat and oats growing in nutrient solutions, found significant amounts of carbon dioxide given off by the roots of plants. *Trifolium pratense* gave off 5.8 grams of carbon dioxide per 100 grams of dry substance in 24 hours. The ratio of carbon dioxide to dry weight of sugar beet roots decreased from 5.44 after 24 days to 1.76 after 50 days, 0.52 after 75 days and to 0.31 after 120 days.

Lau (9) determined the amount of carbon dioxide in the soil air at a depth of 13 to 15 cm. under potatoes, barley, seradella, oats, lupines and

fallow soils, manured and unmanured, during May, June, July and August. The carbon dioxide content of the soil air was higher in the cropped soils than in the fallow soils and it was higher under potatoes and lupines than under barley and oats. The average percentages on the untreated soils were 0.54 for potatoes, 0.44 for lupines, 0.22 for oats and 0.20 for barley.

Stoklasa and Ernest (17) grew oats, wheat, barley, rye and buckwheat seedlings in a nutrient solution 40 to 60 days, then placed the plants in an apparatus under aseptic conditions and determined the amount of carbon dioxide given off by the roots of these plants. Barley roots gave off the largest amount of carbon dioxide but when this was reduced to unit weight of roots it was the smallest of all plants studied. The amount of carbon dioxide given off per unit weight of roots was largest with oats and rye. After 68 days the oat plant gave off 135.4 milligrams of carbon dioxide per gram of roots and after 84 days the amount decreased to 111.5 milligrams per gram of roots in 24 hours. Plants were grown 56 days in powdered minerals and the amount of carbon dioxide evolved per gram of dry roots determined. The oat roots gave off 122.8 milligrams, the barley 70.34 milligrams, wheat 90.35 milligrams and rye 111.37 milligrams.

Barakov (1) found that the carbon dioxide content of the soil air under various crops was low at the beginning of the growing period but it increased rapidly and reached a maximum at the blooming period, then it decreased to a minimum at the period of ripening. The maximum evolution of carbon dioxide by oats, however, was reached about 2 weeks before blooming, and by potatoes after blooming. Barley and wheat gave off less carbon dioxide than oats.

Russell and Appleyard (14) found some differences between the concentration of carbon dioxide in cropped and fallow soils but concluded that the difference was due to soil conditions rather than to the crop.

Leather (10) found larger quantities of carbon dioxide in the soil near plant roots than in bare soil.

Potter and Snyder (13) found an average of 1.80 per cent carbon dioxide in the soil air under timothy, whereas the soil air of an adjacent fallow plot contained only 0.517 per cent of carbon dioxide.

Bizzell and Lyon (2) found striking fluctuations in the carbon dioxide content of the soil air of a Dunkirk clay loam cropped to oats. The greatest apparent production was at the blooming period. Subsequent to the blooming period there was a marked decrease in the content of carbon dioxide. It was concluded that this decrease was caused by a depressing effect of the crop on the production of carbon dioxide by bacterial action. On Volusia silt loam the crop apparently had little effect on the carbon dioxide content.

Turpin (18) found that an oat crop on a Dunkirk clay loam increased the production of carbon dioxide in the soil. This increase became more marked after the first month from the time of seeding, and increased to a maximum just previous to or after the plants headed, after which there was a gradual decrease. Millet produced about the same increase in carbon dioxide in the soil air as did oats but the production of carbon dioxide by each millet plant was approximately half as much as the production by each oat plant. The most marked rise in the carbon dioxide content of the soil air occurred at a later period of growth in the case of the millet than in the case of the oats. It was concluded that the plant itself and the soil organisms produce most of the carbon dioxide in the soil; that the plant often produced at the period of its most active growth many times as much

carbon dioxide as is produced by soil organisms; and that the excess carbon dioxide in the soil growing a crop is due to respiratory activity of the plants rather than to the decay of root particles from the crop growing on the soil at the time of analysis.

Headden (6) found that under irrigation there was a greater concentration of carbon dioxide in the soil air at a depth of 18 inches under grass than under clover and that the carbon dioxide content of the air in fallow soil was lower than that in cropped soil. It was also found that irrigation did not materially increase the carbon dioxide content of fallow soil over the non-irrigated fallow soil.

Lundegardh (11) found that soil covered with oats evolved about 30 per cent more carbon dioxide than the same soil fallow. He also stated that the roots of oats and wheat grown in non-sterile soil evolved about 45 per cent more carbon dioxide per unit of dry substance than roots grown in sterile soil.

Magers (12) determined the concentration of carbon dioxide in the soil air and the evolution of carbon dioxide at the surface of the soil under peas, sugar beets, potatoes, oats, barley, corn, clover and in fallow soil during June, July and August. It was concluded that the respiration or the evolution of carbon dioxide at the surface of the soil depends upon the kind of plants grown. The evolution of carbon dioxide was greatest from the soil under the legumes and least from the soil under potatoes and the cereals. It was also concluded that plants increase the evolution of carbon dioxide from the surface of the soil only so long as the soil is above a certain minimum moisture content.

An analysis of the data in the literature shows that carbon dioxide is given off by the roots of plants and that some plants give off more carbon dioxide than others. In general, though not always, legumes have been found to give off more carbon dioxide than non-legumes. It has also been found that the amount of carbon dioxide given off by the roots of plants increases to a maximum during the period of most active plant growth and then decreases. In some cases, the maximum amount of carbon dioxide given off by the roots of plants occurs during the blooming period, whereas, the maximum is reached earlier or later than the blooming period in the case of other plants. The conditions of the experiments have not always been completely described and conclusions cannot be drawn. For example, no conclusions concerning the carbon dioxide given off by the roots of different plants can be drawn from the work of Boussingault and Lewy. Wollny ascribed the decrease in concentration of carbon dioxide in the soil air of cropped soils to the shading effect of the plants, whereas, Bizzell and Lyon regard it as a detrimental effect of the plant on the microorganisms in the soil.

EXPERIMENTAL

The percentage of carbon dioxide in the soil air under various crops and in fallow soils was determined at weekly intervals during June, July, August and September. The soil under investigation was a rather uniform Carrington loam. The soil air was sampled at a depth of 15 cm. by means of a special tube, figure 1, fitted with a rod sharpened at one end which could be easily pushed into the soil. Ten-cubic-centimeter samples of the soil air were analyzed in a Haldane micro-gas analysis apparatus. The apparatus was supported on a surveyor's plane table when used in the field. Three samples of air were taken for analysis at each location of the tube
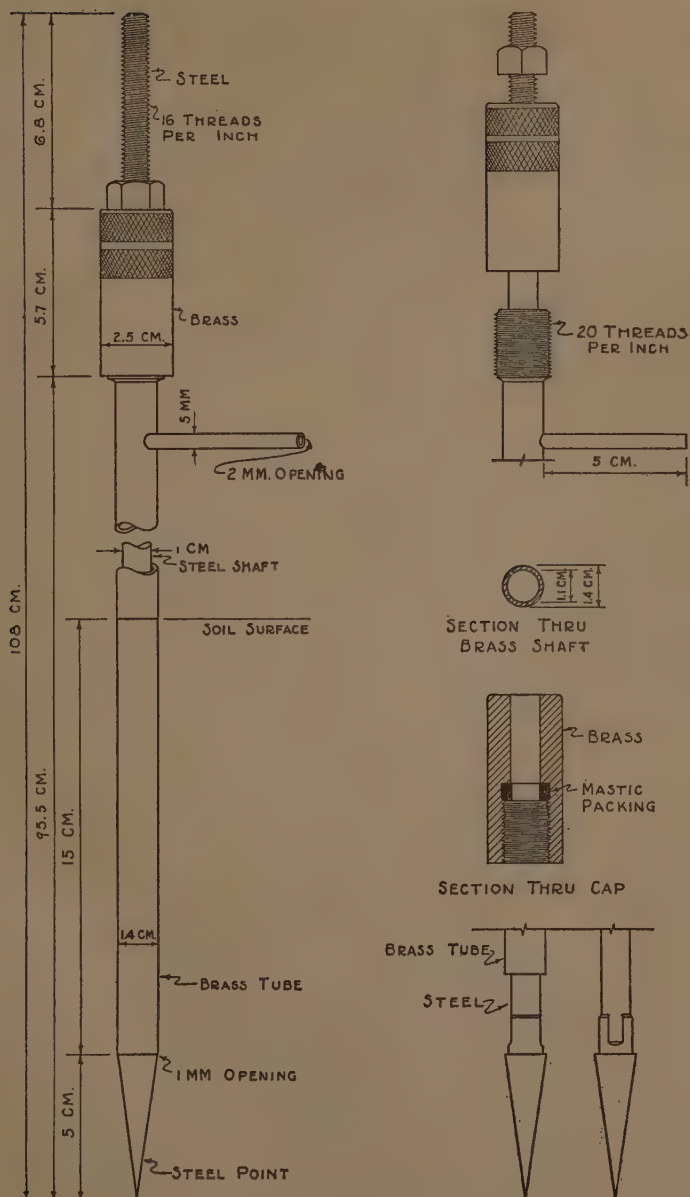
Fig. 1. Tube for sampling soil air.

TABLE 1. *The percentage of carbon dioxide in the air of fallow soils*

Soil treatment	DATE												
	6-20	6-29	7-7	7-12	7-19	7-25	8-5	8-10	8-19	8-24	8-31	9-14	Average
Check	0.75	0.30	0.53	0.23	0.26	0.30	0.34	0.41	1.15	0.42	0.78	0.43	0.49
1500 lbs. per acre red clover	0.47	0.30	0.39	0.32	0.41	0.33	0.45	0.29	0.96	0.30	0.79	0.49	0.46
2400 lbs. per acre sweet clover	0.50	0.23	0.31	0.29	0.13	0.07	0.30	0.20	0.88	0.38	0.66	0.37	0.36
1500 lbs. per acre oat straw	0.52	0.34	0.35	0.37	0.25	0.19	0.41	0.31	0.54	0.38	0.67	0.52	0.40
Average	0.56	0.29	0.40	0.30	0.31	0.22	0.38	0.30	0.88	0.37	0.73	0.45	0.43
Average groups of 4 weeks each			0.39				0.30				0.61		

and at least three locations were made on each plot.   The results given in
the tables are, therefore, the averages of 9 readings.

The percentage of carbon dioxide in the air of fallow soil

A series of small plots, treated with various organic materials and
maintained fallow for one year previous to these studies, was sampled as
described above.   The results obtained are presented in table 1.   The
average concentration of carbon dioxide of the soil air of all soils at the
different sampling was used in the graph in figure 2.
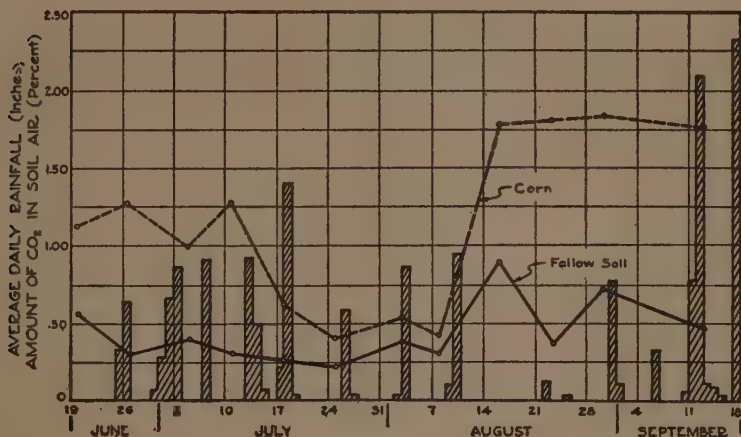
Fig. 2.   The relation between the concentration of carbon dioxide in the soil air and
rainfall.

The percentage of carbon dioxide in the air of the check soil was higher
than that of any of the treated soils on June 20, July 7, August 10, August
19, and August 24, and the average for all readings was significantly higher
for the check than for the soils treated with sweet clover or straw.   Inas-
much as the treatments were made one year previous to the sampling for
analysis it is not likely that the treatments had any appreciable effect on
the concentration of carbon dioxide in the soil air at this time.   These
differences might be ascribed to either local variations in the soil from plot
to plot or to the fact that the concentration of carbon dioxide in the soil
air, being a resultant of various factors, is not an adequate test for de-
tecting small differences in carbon dioxide production in field soils.   These
facts were both brought out in another test made the following year on
the same soils in which the treatments were made May 30 and readings
made at daily intervals beginning June 20.

The average percentage of carbon dioxide in the soil air of all soils
for the period was 0.43 per cent.   The average values obtained at the dif-
ferent samplings did not vary widely from the average of all readings, ex-
cept for the readings made June 20, August 19 and August 31.   These
differences, though usually small, are highly significant.   The date of

TABLE 2. *The percentage of carbon dioxide in the soil air under corn*

Plot No.	Treatment	6-21	6-28	7-5	7-12	7-10	7-25	8-4	8-9	8-19	8-23	8-30	9-14	Aver.
1000a	Check	1.04	1.01	1.01	1.00	0.63	0.37	0.41	0.36	1.69	1.87	1.22	2.09	1.06
1000b	Check	1.30	0.76	0.69	1.00	0.65	0.46	0.47	0.23	1.45	1.89	1.48	1.69	1.00
1001a	Manure	1.32	1.59	0.79	1.02	0.56	0.10	0.41	0.18	2.04	1.79	1.96	1.71	1.12
1001b	Manure	1.00	1.74	0.57	1.12	0.63	0.12	0.25	0.39	1.87	2.26	2.60	1.96	1.21
1002a	Manure + lime	1.64	1.43	1.26	0.72	0.64	0.42	0.37	0.27	1.34	1.92	1.57	2.31	1.16
1002b	Manure + lime	1.47	1.25	0.93	0.83	0.76	0.39	0.68	0.20	2.29	1.29	1.04	2.65	1.15
1003a	Manure + lime + rock phosphate	1.20	2.26	1.00	0.93	0.52	0.33	0.33	0.41	1.71	1.90	2.62	1.67	1.24
1003b	Manure + lime + rock phosphate	0.99	1.68	1.28	1.20	0.93	0.40	0.78	0.34	2.33	1.90	1.93	1.95	1.31
1004a	Manure + lime + superphosphate	0.90	1.32	1.06	1.40	0.32	0.08	0.42	0.38	1.80	1.53	1.12	1.37	0.98
1004b	Manure + lime + superphosphate	0.98	1.04	1.08	1.20	0.63	0.30	0.27	0.48	2.28	2.05	1.54	1.24	1.09
1005a	Check	1.11	1.33	0.90	1.24	0.67	0.50	0.23	0.63	1.32	2.20	1.73	1.97	1.15
1005b	Check	0.70	0.63	0.99	2.26	0.88	0.41	0.74	0.35	2.50	2.73	1.82	2.25	1.36
1006a	Crop residues	0.74	1.66	1.07	0.93	0.64	0.37	0.76	0.38	1.15	1.08	1.51	1.73	1.08
1006b	Crop residues		0.82	0.95	1.09	0.73	0.81	0.73	0.59	1.34	1.76	1.35	1.75	1.08
1007a	Crop residues + lime	1.03	0.84	1.65	1.50	0.85	0.34	0.50	0.59	1.42	2.01	1.93	1.86	1.21
1007b	Crop residues + lime	0.60	1.21	1.24	1.53	0.57	0.60	0.64	0.66	1.68	1.45	1.97	1.33	1.12
1008a	Crop residues + lime + rock phosphate	1.80	0.85	1.09	1.26	0.80	0.42	0.66	0.36	1.09	1.15	1.63	1.76	1.07
1008b	Crop residues + lime + rock phosphate	1.34	0.94	0.76	1.76	1.19	0.54	0.76	0.52	1.44	1.70	2.53	1.21	1.22
1009a	Crop residues + lime + superphosphate	1.12	1.03	1.05	1.17	0.46	0.42	0.45	0.43	2.06	1.60	1.93	1.41	1.09
1009b	Crop residues + lime + superphosphate	0.63	2.00	0.99	1.68	1.03	0.57	0.81	0.34	2.47	1.80	2.44	1.53	1.36
1010a	Check	1.31	1.14	0.58	1.73	0.68	0.21	0.55	0.57	1.38	1.35	2.03	1.65	1.10
1010b	Check	1.27	1.19	0.78	1.20	0.61	0.60	0.51	0.61	2.28	1.20	2.10	1.63	1.17
Average		1.11	1.26	0.99	1.26	0.67	0.40	0.53	0.42	1.77	1.79	1.82	1.76	1.15

a = between rows
b = under rows

sampling was apparently the most important factor in determining the percentage of carbon dioxide in the air of these treated and untreated fallow soils. If the twelve weekly readings are divided into three periods of four weeks each, a highly significant difference is found between the percentage of carbon dioxide in the soil air during the different periods. The percentage of carbon dioxide in the air of all soils was affected similarly and the differences were apparently caused by temperature or a combination of temperature and other weather conditions.

The percentage of carbon dioxide in the soil air under corn

The concentration of carbon dioxide in the soil air under corn was determined on a series of plots in a five-year rotation of corn, oats, clover, wheat and alfalfa. The soil treatments and the percentages of carbon dioxide are shown in table 2. Two locations with respect to the plant were sampled on each plot. One sample of soil air was drawn from near the plant and is designated ''under the row'' and the other sample designated ''between the rows'' was drawn as far from the plant as possible. The corn was planted in checks 42 inches apart.

At the first sampling, June 21, the corn was about 10 inches high. It grew rapidly during the next four weeks and was beginning to tassle July 12. During the next three weeks the corn fired considerably. At this time the ears were well formed and beginning to fill out. The corn was dented, the silks were dead and the shucks were beginning to ripen at the last sampling, September 14. An analysis of variance of the data was made by the method of Fisher (5). The results obtained are presented in tables 2 and 3.

TABLE 3. *Average percentage carbon dioxide in soil air in a-b positions during three periods*

Position	4-week periods			Average for season
	1	2	3	
a — between rows	1.18	0.45	1.71	1.11
b — under row	1.13	0.57	1.86	1.19
Average	1.16	0.51	1.79	1.15

The data in the table show a significant difference between the percentages of carbon dioxide in the soil air under the row and between the rows. There was also a significant change in the relative magnitudes of the a and b readings from date to date and from plot to plot, table 3. The average percentages of carbon dioxide in the soil air between the rows of corn were greater than those under the row during the first four weeks of the experiment but lower during the remaining eight weeks. The high concentration of carbon dioxide in the soil air under the rows during the last eight weeks of the experiment corresponds with the period of maximum growth of the corn. The differences between the a and b readings during the first four weeks are not highly significant but may be explained if one assumes a detrimental effect of the young corn plants on the activity of the microorganisms in the vicinity of the corn roots. There was a small but insignificant difference between the means of all checks and all treatments, the former being larger than the latter. This would, as was shown in the case of fallow soils, indicate no effect of treatments on the content of carbon dioxide in the soil air.

The percentage of carbon dioxide in the soil air under various crops

The concentration of carbon dioxide in the soil air under cowpeas, soy beans, alfalfa, red clover, wheat, oats and blue grass was determined as described above at weekly intervals from June 20 until September 13. Samples of soil air for analysis were taken from under the row and between the rows of cowpeas and soy beans. The samples of soil air for analysis from alfalfa, red clover, wheat and oats were taken from a check plot and an adjacent manured plot. The results obtained are presented in table 4 and the averages of all readings for each crop in figure 3.
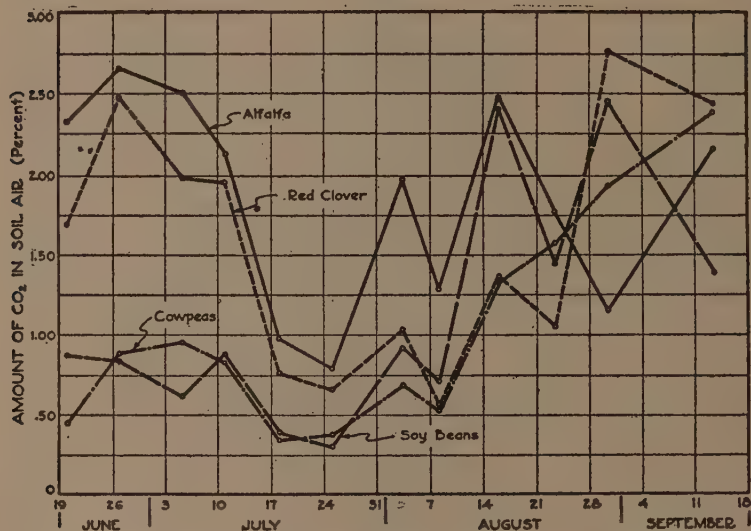
Fig. 3. The concentration of carbon dioxide in the soil under various crops.

At the first sampling, June 20, the alfalfa had just been cut the first time. The red clover was in bloom and wheat and oats were just headed out.

At the July 5 sampling the alfalfa was about 12 inches high, the red clover was about 8 inches high and the wheat had been harvested.

The oats had been harvested at the July 11 sampling. The alfalfa was being cut a second time. The red clover was about 10 inches high.

The soy beans were in bloom at the July 25 sampling, the stand of alfalfa was thin and the red clover was in bloom. There was no clover in the wheat or oat stubble.

At the August 3 sampling, soy bean pods were forming, cowpeas were in bloom and red clover was ripening. Alfalfa was about 8 inches high.

The red clover was being cut at the August 8 sampling. The alfalfa was beginning to bloom.

At the August 16 sampling the cowpeas and soy beans were ripening. The alfalfa was cut the third time during the week of August 30. The red clover was about 10 inches high.

The results in the table show that the difference in the percentage of

TABLE 4. *The percentage of carbon dioxide in the soil air under various crops and different treatments*

Plot No.	Crop	Treatment	DATE												
			6-20	6-27	7-5	7-11	7-18	7-25	8-3	8-8	8-16	8-23	8-30	9-14	Average
900a	Soy beans	Check	1.18	1.01	0.57	0.77	0.29	0.31	0.86	0.84	2.40	1.71	2.39	1.13	1.04
900b	Soy beans	Check	0.55	0.62	0.63	0.95	0.47	0.29	0.94	0.59	2.40	1.15	2.47	1.60	1.06
901a	Cowpeas	Check	0.28	0.85	1.18	0.47	0.31	0.28	0.75	0.52	1.09	1.26	0.85	2.36	0.85
901b	Cowpeas	Check	0.61	0.91	0.71	1.15	0.37	0.46	0.64	0.51	1.55	1.83	3.00	2.40	1.18
817	Red clover	Check	1.61	2.80	2.18	2.30	0.74	0.61	1.01	0.73	1.33	1.20	3.50	3.05	1.76
818	Red clover	Manure	1.76	2.16	1.76	1.60	0.76	0.68	1.01	0.38	1.36	0.86	1.99	1.83	1.35
924	Alfalfa	Check	1.81	2.50	2.00	2.40	1.05	0.59	1.65	1.21	2.45	1.86	1.36	1.49	1.70
925	Alfalfa	Manure	2.80	2.80	3.00	1.84	0.88	0.95	2.26	1.31	2.48	1.66	0.94	2.80	1.98
805	Oats	Check	1.41	1.77	0.40	0.89	0.91	0.38	.	.	.	.	.	.	0.96
806	Oats	Manure	1.73	1.77	0.75	1.47	0.74	0.23	.	.	.	.	.	.	1.12
804	Wheat	Check	0.57	2.28	1.01	1.55	0.39	0.07	.	.	.	.	.	.	1.08
808	Bluegrass		0.18	0.78	0.79	0.26	0.10	0.06	0.19	0.17	1.12	0.47	0.07	0.50	0.39

carbon dioxide in the soil air under the row of soy beans and between the rows was not significant. However, the trend in the four-week intervals was similar to that in corn. In the case of cowpeas, there was a significant difference but the trend found in the four-week intervals was different from that found in corn and soy beans.

The average percentage of carbon dioxide in the soil air was higher in the manured plot than in the check plot in the case of alfalfa but the check plot averaged higher in carbon dioxide content in the case of red clover. The means of the two checks compared with the means of the two manured plots show a small but significant increase in carbon dioxide content of the soil air on the check plots. There was also a change in the trend during the four-week periods in the case of red clover and alfalfa, the highest concentration being found during the first period, whereas, in the case of all other crops, the highest concentration of carbon dioxide was found in the soil during the last four weeks of the experiment.

This is no doubt explained by the fact that these crops are perennial and the first period of the investigation corresponds with the period of maximum growth of these crops. The notes taken on the condition of the crops throughout the season show that both alfalfa and red clover made poor growth during the latter part of the period.

The average percentage of carbon dioxide in the soil air under blue grass sod was 0.39 and the same trend was shown during the four-week periods as was shown in the case of corn and fallow soils.

The data for all treatments of each crop and the fallow soils were averaged and the results presented in table 5 and in figures 2 and 3.

The average percentage of carbon dioxide in the soil air was highest under alfalfa, 1.84 per cent, and 1.55 per cent under red clover. The amount of carbon dioxide under the other crops, corn, soy beans and cowpeas were about the same, being slightly above 1 per cent. The average percentages for blue grass sod and fallow land were 0.39 and 0.43 per cent, respectively. The averages for oats and wheat are not comparable with the other crops because the period of maximum growth and harvest occurred before and during the first half of the experiment.

An analysis of variance of the data for all crops shows a significant difference between the concentration of carbon dioxide in the soil air under the various crops. The following groups may be recognized:

1. Blue grass—fallow
2. Soy beans, cowpeas and corn
3. Red clover and alfalfa

DISCUSSION

Small but significant variations were observed in the carbon dioxide content of the soil air of variously treated plots and the variations from plot to plot were not, apparently, attributable to treatment but indicate local variations in soil which produce greater differences than treatment. The results emphasize the limitations of the method for determining the production of carbon dioxide in the soil.

In general, the concentration of carbon dioxide in the soil air of the cropped soils followed much the same trend as it did in the fallow soils. The greatest variation in carbon dioxide content of the soil air occurred from date to date and in a similar way with all crops and treatments. The amount of moisture in the soil was not determined regularly but from the rainfall data in table 6 and figure 2, it is evident that the fluctuations in

TABLE 5. *Average percentage of carbon dioxide in the soil air under various crops*

Crop	DATE												Average
	6-20	6-27	7-5	7-11	7-18	7-25	8-3	8-8	8-16	8-23	8-30	9-13	
Corn	1.11	1.26	0.99	1.26	0.67	0.40	0.53	0.42	1.77	1.79	1.82	1.76	1.15
Oats	1.57	1.77	0.58	1.18	0.83	0.31	.	.	.	.	.	.	1.04
Wheat	0.57	2.28	1.01	1.55	0.39	0.07	.	.	.	.	.	.	1.08
Soy beans	0.87	0.82	0.60	0.86	0.38	0.30	0.90	0.72	2.40	1.43	2.43	1.37	1.05
Cowpeas	0.45	0.88	0.95	0.81	0.34	0.37	0.68	0.52	1.32	1.55	1.93	2.38	1.01
Red clover	1.69	2.48	1.97	1.95	0.75	0.65	1.01	0.56	1.35	1.03	2.75	2.44	1.55
Alfalfa	2.31	2.65	2.50	2.12	0.97	0.77	1.96	1.26	2.47	1.76	1.15	2.15	1.84
Bluegrass	0.18	0.78	0.79	0.26	0.10	0.06	0.19	0.17	1.12	0.47	0.07	0.50	0.39
Fallow	0.56	0.29	0.40	0.30	0.26	0.22	0.38	0.30	0.88	0.37	0.73	0.45	0.43

carbon dioxide content of the soil air were not directly related to rainfall and hence it may be assumed not to the moisture content of the soil. A low rate of production during the intermediate weeks or an increased diffusion velocity would account for the lower percentages of carbon dioxide in the soil air during this period. Much higher soil temperatures prevailed during the second and third periods than during the first and undoubtedly had some effect on the values obtained. The rate of diffusion and solution of carbon dioxide as well as the rate of production and soil variability apparently masked any large differences in concentration due to the soil treatments.

TABLE 6. *Average daily rainfall in inches during the summer of 1932*

Date	Month			
	June	July	August	September
1	0	0.28	0	0.10
2	0.08	0.67	0.02	*
3	0.41	0.87	0.87	0
4	0.67	*	0	0
5	0.32	0	0	0
6	0.12	0	*	0.33
7	0.83	0.90	*	0
8	0.12	*	0	0
9	*	0	0.10	*
10	0	0	0.92	0.07
11	0	0	0	1.02
12	0	0	0	2.10
13	0	0.91	0	0.10
14	0	0.49	0	0.09
15	1.21	0.08	0	0.02
16	0.15	0	*	0
17	*	0.21	0	2.55
18	0	1.40	0	0
19	0	0.02	0	0
20	0	0	0	0
21	0	0	*	0
22	0	0	0.12	0
23	0	0	0	0
24	*	*	0	0
25	0.33	0	0.02	0.51
26	0.65	0.59	0	0
27	0	0.02	0	0.29
28	0	0	0	0.33
29	0	0	0	0
30	0.08	0	0	*
31		0	0.77	

* Trace

These data show that the carbon dioxide was produced by the microorganisms and the roots of the crop plants, assuming a constant and small amount to be produced by chemical reaction. A higher production of carbon dioxide by the roots of all leguminous plants than by the non-leguminous plants was not observed. However, the deeper rooted legumes, alfalfa and red clover, apparently produced more carbon dioxide than the shallow rooted plants. It cannot be assumed that the rate of diffusion was the same in the soils under all the crops since the moisture relations were not necessarily the same under the different crops. However, the difference in concentration of carbon dioxide in the soil air caused by such differences in

rate of diffusion would not account for the large percentage concentration found under soy beans and cowpeas during the ripening period of these crops. It is also unlikely that these plants would be evolving carbon dioxide so much more rapidly during this period than during the period of maximum growth. It would seem more likely at this stage that the microorganisms were more active due to stimulation by the plant, perhaps the decomposition of dead roots or nodules. A depressing effect on the soil microorganisms was apparently brought about by the blue grass since it is not likely that the rate of diffusion under blue grass would be so much greater than in fallow soil. The decreased concentration of carbon dioxide in the soil air under all crops and especially under corn from July 11 to August 8 was apparently due to an increased diffusion rate, temperature effect and to less active respiration of the roots of the plants rather than to a depressing effect of the crop on the soil microorganisms or decreased microbiological action. The variations in the carbon dioxide content of the soil air under red clover and alfalfa appeared to be related more to the stage of development of the plant than to the time the crop was cut. If harvesting the crop was delayed beyond the blooming stage, the decrease in carbon dioxide occurred before harvest. Headden (6) observed a decrease in the carbon dioxide content of the soil after harvest and concluded that in cutting the clover, growth was not only retarded but that the plant apparently exerted a depressing effect on the microorganisms. From these data it would seem that the fluctuations in carbon dioxide content of the soil air under these crops were due to a decreased activity of the plant. The concentration of carbon dioxide in the soil air under wheat and oats was not followed from the time of seeding but the observations began about the time the plants were beginning to head. After these crops were harvested, the concentration of carbon dioxide gradually decreased to about the same level as that of the fallow soil.

SUMMARY AND CONCLUSIONS

The concentration of carbon dioxide in the soil air in fallow soil and in soils under different crops and various soil treatments was determined during the period June 20 to September 14. Significant differences were observed between the percentage content of carbon dioxide in the soil air of variously treated soils under corn but the differences were not large. Significant differences were also observed in the content of carbon dioxide in the soil air under different crops. The data show in some cases a stimulating effect of the plants on microbiological action in the soil. A slight depressing effect of blue grass on microbiological action was indicated. The general conclusion that all legumes produce more carbon dioxide than other crops seems unwarranted. The deeper rooted legumes, alfalfa and red clover, produce larger amounts of carbon dioxide than the shallow rooted cowpeas and soy beans. The cereals and the shallow rooted legumes, cowpeas and soy beans, produce about the same amounts of carbon dioxide but the legumes may stimulate microbiological action to a greater extent than the cereals. The concentration of carbon dioxide in the soil air as a measure of the rate of carbon dioxide production in field soils is of limited value and is generally not a desirable method for detecting differences due to soil treatment, unless the experiment is especially planned to eliminate the other variations which occur between apparently uniform soils.

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A COMPARATIVE ANALYSIS OF THREE HUNDRED FABRICS

RACHEL EDGAR

This study of the construction and mechanical performance of medium grades of typical and staple fabrics was undertaken to gain definition by quantitative description. Repeated consideration has been given fabrics of similar construction but different names, different grades of a fabric, and fabrics at different stages of manufacture.

Professor O. Settles of the Department of Textiles and Clothing, Iowa State College, suggested the study and most generously selected and acquired about one-third of the fabrics. Many have given fabrics and help in obtaining fabrics and forty-two of the fabrics were analyzed in this laboratory by Miss Ida Anders (fabrics 91, 160, 234, and 243), Miss Florence Barr (fabric 291), Miss Mildred Barr (fabrics 21, 45, 171, and 296), Miss Eleanor Fisher (fabrics 150 and 178), Miss Margaret Furry [3, 4, 5],[1] (fabrics 26, 48, 98, 100-103, 107, 109-116, 120, 124, 189, and 195), Miss Ruth Gerber (fabric 285), Miss Marion Griffith [7], (fabric 62), Mrs. Donald MacKay [8], (fabric 44), Miss Jeanette Ross (fabric 299), Miss Thelma Sprague [7], (fabrics 221-224), Mrs. Paul Van Ess (fabric 51), Mrs. Arthur Walde (fabric 263), and Mrs. Arthur Young [7], (fabric 81).

The fabrics, as indicated in table 1, are considered in the order of the following classification:

A. Fabrics of fibrous structure (fabric 1)
2A. Fabrics constructed of yarns
    B. Fabrics of one series of yarns
        C. Laid fabrics[2] (fabric 2)
        2C. Plaited fabrics[3] (fabrics 3 and 4)
        3C. Knitted fabrics[4]
            D. Simple knitted fabrics
                E. Chain-stitched fabrics (fabric 5)
                2E. Filling knitted fabrics
                    F. Plain flat filling knitted fabrics (fabrics 6 and 7)
                    2F. Rib filling knitted fabrics (fabric 8)
                3E. Warp knitted fabrics (fabric 9)
            2D. Plated flat filling knitted fabrics (fabrics 10 and 11)
    2B. Fabrics of more than one series of yarns
        C. Net fabrics formed of yarns arranged in meshes
            D. Fabrics of hexagonal mesh (fabrics 12-14)
            2D. Fabrics of square mesh (fabric 15)

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[1] Literature references are indicated by [ ].

[2] The yarns of laid fabrics are held in parallel relationship by means of a binding material.

[3] Plaited fabrics are formed by the interlacement of one series of yarns.

[4] Knitted fabrics are made on more than one needle by interlooping one yarn or several parallel yarns.

2C. Woven fabrics[5]

    D. Fabrics in which systems of parallel yarns interlace only at right angles

        E. Fabrics in which one system of parallel yarns is interlaced at right angles with a second system of parallel yarns

           F. Fabrics of plain weave[6]

              G. Fabrics of simple plain weave (fabrics 16-143)

              2G. Fabrics of figured plain weaves (fabrics 144-146)

              3G. Fabrics of derived plain weaves

                  H. Fabrics of simple rib weaves

                      I. Fabrics of simple warp rib weaves[7] (fabrics 147-151)

                      2I. Fabrics of simple filling rib weaves[8] (fabric 152)

                2H. Fabrics of fancy rib weaves

                      I. Fabrics of fancy warp rib weaves[9] (fabrics 153-156)

                      2I. Fabrics of fancy filling rib weaves[10] (fabrics 157-163)

                3H. Fabrics of combinations of warp rib and filling rib weaves

                      I. Fabrics of basket, checker, hopsack, or matt weaves

                          J. Fabrics of simple basket weaves[11] (fabrics 164-166)

                          2J. Fabrics of fancy basket weaves[12] (fabrics 167-170)

                      2I. Fabrics of oblique rib weaves[13] (fabric 171)

[5] Woven fabrics are formed by some definite arrangement of interlacement at right angles of one set of systems of parallel yarns or flexible strips with a second set of systems of parallel yarns. The systems of yarn lengthwise of the fabric are the warp systems; those at right angles to the warp yarns are the filling systems. Weaves are designated by the order in which the first warp yarn of a repeat, the smallest number of warp and filling yarns which gives the complete order of interlacement, interlaces with the filling yarns.

[6] The plain, calico, cotton, tabby, or taffeta weave is a pattern in which each yarn in each series passes alternately over and under consecutive yarns of the other series.

[7] Ribs of warp, long ribs, are formed by the alternate passing of every filling yarn over and under two or more warp yarns.

[8] Ribs of filling, cross ribs, are formed by the alternate passing of every warp yarn over and under two or more filling yarns.

[9] Fancy warp rib weaves are combinations of warp rib and plain weaves.

[10] Fancy filling rib weaves are combinations of filling rib and plain weaves.

[11] Simple basket weaves are cominations of simple rib weaves of the same warp and filling effects.

[12] Fancy basket weaves are combinations of simple rib weaves of different warp and filling effects or combinations of fancy rib weaves.

[13] One repeat of an oblique rib weave is formed by alternately filling the eight right triangles which meet at the center of a square, or the triangles formed by pairs of these triangles, with warp rib and filling rib effects.

2F. Fabrics of twill weaves[14]

 G. Fabrics of simple twill weaves

  H. Fabrics of 1/2, Cashmere, Genoa, or sacking twill weave (fabrics 172-177)

  2H. Fabrics of 2/1, Gloria, Jeanette, or Prunella twill weave (fabrics 178-186)

  3H. Fabrics of 2/2, Batavia, blanket, cassimere, Celtic, common, Harvard, serge, shalloon, or sheeting twill weave (fabrics 187-199)

  4H. Fabrics of 1/3 or swansdown twill weave (fabric 200)

  5H. Fabrics of 3/1 or crow twill weave (fabrics 201 and 202)

  6H. Fabrics of 1/4, Beatrice, or Italian twill weave (fabrics 203 and 204)

  7H. Fabrics of 4/1 twill weave (fabric 205)

  8H. Fabrics of 3/3 twill weave (fabric 206)

 2G. Fabrics of derived twill weaves

  H. Fabrics of twill weaves of one diagonal

   I. Fabrics of steep, elongated, diagonal, or round twill weaves (fabrics 207 and 208)

   2I. Fabrics of combination or double twill weaves (fabrics 209 and 210)

   3I. Fabrics of rearranged twill weaves

    J. Fabrics of skip, non-continuous, or offset twill weaves (fabric 211)

    2J. Fabrics of corkscrew twill weaves (fabrics 212-215)

    3J. Fabrics of satin weaves[15]

     K. Fabrics of simple satin weaves (fabrics 216-238)

     2K. Fabrics of derived satin weaves

      L. Fabrics of double satin weaves[16] (fabric 239)

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[14] The twill, croisé, or serge weave is a pattern in which each successive filling yarn interlaces correspondingly, but not alternately, with successive warp yarns and develops a distinct diagonal across the fabric. A twill is termed regular, steep, or reclining according as the angle at which it crosses the fabric is forty-five degrees, greater, or less [11]. Twills are designated as right or left according as the diagonal lies to the right or to the left of the filling yarn (viewed from the opposite selvage) at right angles to the selvage at the point of intersection of the diagonal and the selvage [9]. The diagonal of the twill is emphasized by filling yarns of the same direction of twist as the twill and by warp yarns of the opposite direction of twist. Balanced twills show warp and filling yarns to the same extent on each surface of a fabric; either warp or filling yarns predominate on surfaces of uneven twills.

[15] The rearrangement of a continuous twill weave to form a regular smooth-faced satin weave is accomplished by such distribution of the interlacements that these will be more or less obscured by adjacent yarns. The number of warp yarns the point of interlacement advances every successive filling yarn of a regular satin is the counter, either of the numbers obtained upon division of the number of warp yarns in the repeat into two unequal parts of no common divisor.

[16] Double satin derivatives of regular satin weaves have twice the interlacement of warp and filling yarns in one repeat.

2L. Fabrics of crêpe, granite, oatmeal, or pin-head weaves (fabrics 171, 240, and 241)

2H. Fabrics of transposed twill weaves, of more than one diagonal
    I. Fabrics of angle, arrowhead, chevron, feather, herringbone, pointed, saw-toothed, wavy, or zigzag twill weaves
        J. Fabrics of simple pointed twill weaves (fabrics 242 and 243)
        2J. Fabrics of fancy pointed twill weaves (fabrics 244-247)
    2I. Fabrics of broken, entwining, or interlacing twill weaves (fabrics 248 and 249)
    3I. Fabrics of curved, deflected, serpentine, or undulating twill weaves (fabric 250)

2E. Fabrics in which two systems of parallel yarns are interlaced at right angles with a third system of parallel yarns
    F. Fabrics of backed weaves[17]
        G. Warp-backed fabrics formed of two sets of warp yarns and one set of filling yarns (fabrics 251-258)
        2G. Filling-backed fabrics formed of one set of warp yarns and two sets of filling yarns (fabrics 259-267)
    2F. Pile fabrics[18]
        G. Warp pile fabrics (fabrics 268-275)
        2G. Filling pile fabrics (fabrics 276-280)

3E. Fabrics formed of two sets of warp yarns and two sets of filling yarns
    F. Ply or sandwich fabrics (fabrics 281 and 282)
    2F. Fabrics of double construction
        G. Loose-back fabrics
            H. Fabrics of a reverse surface of floating yarns (fabric 283)
            2H. Blister, doubly transposed, or stitched fabrics (fabric 284)
        2G. Fast-back fabrics (fabrics 285-287)

4E. Fabrics formed of two sets of warp yarns and three sets of filling yarns
    F. Half-fast-back fabrics (fabric 288)
    2F. Wadded blister fabrics (fabric 289)

5E. Fabrics formed of three sets of warp yarns and two sets of filling yarns (fabric 290)

2D. Fabrics in which a system of parallel warp yarns interlaces at right angles with a system of parallel filling yarns and is crossed with yarns of another warp system
    E. Full, plain, or simple gauze fabrics (fabrics 291-295)
    2E. Fancy gauze or leno fabrics, combinations of gauze and plain weaves (fabrics 296-300)

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[17] Backed-weave constructions are used to increase the bulk, strength, or weight of a fabric, to figure the fabric, or to make the fabric reversible.

[18] The foundation of a pile fabric is covered partly or completely with short projecting ends or loops formed by another system of yarns, the pile.

METHODS OF ANALYSIS

Asbestos, the plant fibers, and the wools were identified microscopically. Silk was distinguished from rayon by Millon's test. The solubility of cellulose acetate rayon in acetone was used to distinguish this rayon from the regenerated celluloses. Copper and silver were identified by the usual procedures of qualitative analysis.

For the estimation of the wool of union textiles samples of approximately five grams were dried at from 105° to 110°C. until constant within four-tenths of a milligram (weighed by the method of tares) and treated with 500 cc. of 0.5 N sodium hydroxide at 90°C. and constant volume for 15 minutes. The residues of regenerated cellulose or jute were washed with 300 cc. of water, 200 cc. of one per cent acetic acid, and with several portions of hot water, dried at room temperature, and heated again to constant weight. The loss in weight, corrected for the amount of regenerated cellulose or jute dissolved in blank determinations, was calculated as the percentage of wool in the mixture. The values reported are the averages of two or more determinations which checked within 0.5 per cent [2].

The lengths of ten individual fibers were measured with an accuracy of one-sixteenth of an inch by means of a calibrated steel scale. The average of these ten measurements is reported as the length of the fiber.

Ten determinations were made of the number of twists per two-inch lengths of yarn by means of the Precision Twist Counter. The average number of twists per inch of yarn, the deviation from this average, and the direction [1] of twist are reported.

Two ten-yard lengths of yarn were conditioned and weighed to the nearest milligram. From the average of these weights the number of yards of yarn per pound was calculated.

The number of yarns of each kind per inch was counted in five different places six inches apart in the fabric and not within one inch of the selvage. The average of these five counts is reported as the number of yarns per inch of fabric [1].

A sample of fabric two inches square was conditioned, weighed, and ravelled into yarns. Each kind of yarn was then weighed separately and the percentage of yarn was calculated from the average of two determinations.

Two samples, each from different parts of the fabric, of approximately the same area, not less than four inches in length and of the entire width of the fabric, were conditioned, weighed to the nearest milligram, and measured. The average of these two determinations was taken as the basis of calculation for the weight in ounces of a square yard of the fabric [6].

Ten measurements of the thickness of a fabric were made at different portions of the fabric, exclusive of fabric within six inches of the selvage, by means of a micrometer which pressed upon a circle of fabric, three-eighths of an inch in diameter, with a pressure of six ounces. The thickness reported is the average thickness in inches [1].

The width of a fabric was determined by laying the fabric without tension on a flat surface and measuring, with a calibrated steel scale, the distance from edge to edge at right angles to the length with an accuracy of one-sixteenth of an inch. The width reported is the average of five measurements made at different places in the fabric [1].

A sample of approximately five grams of fabric containing no selvage was placed in a weighing bottle and dried at from 105° to 110°C. until con-

stant. The fabric was then boiled at constant volume for one hour in 500 cc. of distilled water, rinsed, dried in the air, and finally dried to constant weight. The loss in weight was calculated as the percentage of water-soluble substances. The value reported in each case is the average of two determinations which checked within 0.4 per cent.

A sample of approximately five grams of fabric containing no selvage was placed in a weighing bottle and dried at from 105° to 110°C. until constant. The fabric was then ignited to constant weight in a porcelain crucible at a dull red heat in an electric furnace. The percentage of ash was calculated from the average of two determinations which checked within 0.12 per cent.

Yarns were drawn in each of the cellulosic fabrics, not within three inches of the selvage, outlining a square ten by ten inches. This sample was then immersed in boiling distilled water, boiled for thirty minutes at constant volume, transferred to distilled water at room temperature for thirty minutes, removed, dried at room temperature, and pressed without stretching. The square was again measured and the percentage of change in length and in width was calculated as shrinkage [6].

Twenty samples (four by six inches) with the long dimension of the direction of the warp and twenty samples with the long dimension of the direction of the filling were cut from the fabric, exclusive of fabric within one inch of the selvage, so that, in case the width of the fabric permitted, no two samples of any ten in the same direction included the same yarns in that direction. Ten samples from the warp direction and ten from the filling direction were conditioned before testing; ten of the warp and ten of the filling were saturated with distilled water for five minutes before testing. The clamps of the jaws of the Scott Universal Tester (one-inch front jaws and two-inch back jaws) were fastened three inches apart in the body of the sample so that the same yarns were held by both pairs of jaws in the direction of strain. The sample was strained to the breaking point, the pulling jaw traveling at a speed of twelve inches per minute. A record of the stress-strain curve was made by the Autographic Recorder. The average breaking strength in pounds, the deviation from this average, and the average elongation at the breaking load were calculated for conditioned and for wet fabrics [1].

The weight of yarns and fabrics and the breaking strength and elongation were determined for samples conditioned for four or more hours at 70° ± 3°F. and 65 ± 3 per cent relative humidity. The humidity was read from a hygrodeik placed three feet in front of a fan and calibrated by the chemical method [10].

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Twist Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
	A. Fabrics of fibrous structure								
1	Felt	wool	—	W					
				F					
	C. Laid fabrics								
2	Ribbonzine (Pl. IA)	silk	continuous	W single	0	—	—	—	100.0
				F					
	2C. Plaited fabrics								
3	Braid (Pl. IIA)	cotton	1.1	W 2-ply	17L, 13R	6, 7	8,820	2.7	1.6
		regenerated cellulose	continuous	W multi-filament	0	—	7,875	85.8	98.4
				F					
4	Wicking (Pl. IIB)	cotton	0.9	W 4-ply	5L, 4R	10, 18	1,016	14.0	100.0
				F					
	E. Chain-stitched fabrics								
5	Padding	cotton	1.2	W 2-ply	14L, 9R	4, 12	6,653	5.0	10.0
	(Pl. IIC)	cotton	0.9	F roving	0	—	57	3.0	90.0
	F. Plain flat filling knitted fabrics								
6	Jersey, hollow regenerated	regenerated			W			44.0	
	regenerated cellulose rayon	cellulose	continuous	F multi-filament	2L	10	15,397	49.0	100.0
7	Jersey, wool			W				27.0	
	(Pl. IID)	wool	2.6	F woolen	8R	3	13,389	35.0	100.0
	2F. Rib filling knitted fabrics								
8	Balbriggan or			W				29.0	
	Stockinette (Pl. IIE)	cotton	1.2	F single	12R	3	22,907	32.0	100.0
	2E. Warp knitted fabrics								
9	Chamoisette (Pl. IB)	cotton	—	W single	—R	—	—	64.0	100.0
				F				48.0	
	2D. Plated flat filling knitted fabrics								
10	Astrakhan			W				18.0	
	(Pl. IC)	cotton	0.9	Fg single	11R	11	15,960	16.0	43.8
		wool	4.4	Fp 2-ply loop	2L, 2R	25, 15	770	8.0	54.9
				W				24.0	
11	Puttee or	cotton	0.9	Fg single	16R	6	20,479	32.0	48.7
	Fleeced knit	cotton	0.7	Fpl single	—L	—	3,150	32.0	51.1
	D. Fabrics of hexagonal mesh								
12	Bobbinet	cotton	0.9	W 2-ply	22L, 15R	15, 12	13,801	32.0	37.3
	(Pl. IIF)	cotton	0.9	F 2-ply	31L, 19R	10, 14	21,689	26.0	62.7
13	Malines	silk	continuous	W single	—	—	—	28.2	—
		silk	continuous	F single	—	—	—	20.8	—
14	Tulle or	silk	continuous	W single	—	—	—	81.0	—
	Illusion	silk	continuous	F single	—	—	—	108.0	—
	2D. Fabrics of square mesh								
15	Filet (Pl. IIG)	cotton	1.3	W 5-ply novelty	25R, 9L, 17L, 41L, 13R	4, 7, 8, 2, 5	11,340	60.0	60.5
		cotton	1.3	F 2-ply	15L, 11R	9, 11	22,361	28.0	39.6
	G. Fabrics of simple plain weave (Fig. 1 A)								
16	Airplane cloth	cotton	1.1	W 2-ply	17L, 24R	10, 8	22,697	81.0	51.9
		cotton	1.2	F 2-ply	16L, 15R	6, 10	23,789	82.0	49.6
17	Albatross	wool	4.1	W worsted	14R	8	19,908	50.5	63.1
		wool	3.0	F worsted	16R	12	30,979	41.0	36.5

* These abbreviations have been used in describing yarns: b, binding; f, figuring; F, filling; g, ground; L, left twist; o, obverse; p, pile; pl. plating; r, reverse; R, right twist; t, tuck; w, wadding; W, warp; wh, whip.

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation at breaking load Dry pctg.	Wet pctg. of dry
1	6.83	0.0291	37.5	bleached	1.6	1.0	—	57	4	77	50	176
							—	39	8	—	80	—
2	1.04	0.0025	0.2	dyed, sized	13.2	0.6	—	4	35	—	2	—
							—	—	—	—	—	—
3	6.64	0.0102	0.8	bleached	0.2	0.2	0.0	—	—	—	—	—
							0.0	—	—	—	—	—
4	14.66	0.0501	3.3 tubular		2.3	1.1	—	—	—	—	—	—
							—	—	—	—	—	—
5	32.92	0.1171	35.8		—	1.0	—	20	8	134	33	91
							—	16	8	319	30	83
6	4.33	0.0153	35.3		0.7	0.3	3.6	—	—	—	—	—
							+18.0	—	—	—	—	—
7	5.54	0.0179	58.0 tubular		2.3	1.0	—	—	—	—	—	—
							—	—	—	—	—	—
8	3.67	0.0136	26.0 tubular	bleached	0.3	0.2	0.8	—	—	—	—	—
							+15.0	—	—	—	—	—
9	5.55	0.0182	40.5	dyed, suède	1.0	0.3	11.4	—	—	—	—	—
							+10.2	—	—	—	—	—
10	16.22	—	54.0	dyed, pile on reverse alternate courses	0.7	0.5	—	—	—	—	—	—
							—	—	—	—	—	—
11	11.07	0.0415	41.0 tubular	napped	0.8	0.3	6.8	—	—	—	—	—
							0.0	—	—	—	—	—
12	1.76	0.0131	45.0	bleached, sized	1.9	0.4	10.3	15	8	147	17	182
							3.8	14	14	107	44	65
13	0.17	0.0031	27.0	sized	64.7	0.5	—	<1	—	—	—	—
							—	<1	—	—	—	—
14	0.29	0.0036	56.0	bleached	12.8	1.1	—	<1	—	—	—	—
							—	<1	—	—	—	—
15	1.57	0.0125	43.0	bleached	0.2	0.3	5.1	12	9	117	22	173
							0.0	9	13	144	50	156
16	4.39	0.0095	36.5	mercerized	1.6	0.2	7.6	88	5	125	17	194
							2.9	100	4	109	5	220
17	2.38	0.0086	35.0	bleached	2.8	0.6	—	23	3	83	33	182
							—	9	4	88	17	329

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber		Yarn					
		Classification	Length	Construction	Twist		Count	No. per in. of fabric	Pctg. of fabric
						Deviation			
			inch		no. per in., direction	pctg.	yds. per lb.		
18	Alpaca, Mohair, or Sicilian	cotton	1.0	W single	25R	3	38,522	66.5	30.6
		wool	3.9	F worsted	10R	18	16,044	58.0	68.0
19	Argentine or Near glass	cotton	—	W single	—	—	—	23.5	—
		cotton	—	F single	—	—	—	23.0	—
20	Asbestos cloth	asbestos, cotton	1.3	W 2-ply combination	4L, 1R	35, 50	490	19.0	68.3
		asbestos, cotton	1.3	F 2-ply combination	6L, 2R	6, 30	500	9.6	31.7
21	Bagging	cotton	0.9	W 6-ply	5L, 9R	6, 12	1,059	10.0	51.3
		cotton	1.0	F 6-ply	4L, 9R	7, 8	1,028	9.0	48.7
22	Balloon envelope	cotton	1.4	W single	14R	10	118,692	134.0	—
		cotton	1.3	F single	11L	10	89,628	122.0	—
23	Batiste, cotton	cotton	1.6	W single	35R	3	78,750	115.0	57.7
		cotton	1.5	F single	36R	5	108,990	107.0	41.9
24	Batiste, wool, or Nun's veiling	wool	3.0	W worsted	16R	8	24,452	63.7	54.3
		wool	2.2	F worsted	17R	6	29,400	61.6	44.2
25	Bengaline, moiré	silk	continuous	W single	0	—	154,140	194.0	20.3
		wool	1.9	F 3-ply worsted	22L, 6R	8, 5	7,989	39.5	78.5
26	Blanket, cotton	cotton	1.0	W single	13R	15	6,300	44.8	27.5
		cotton	1.0	F single	6R	15	4,452	30.6	72.1
27	Brattice cloth	jute	4.2	W single	4R	10	1,056	12.5	41.8
		jute	5.5	F single	2R	5	858	18.5	57.6
28	Broadcloth, silk	spun silk	—	W 2-ply	12L, 12R	24, 12	48,560	108.0	66.8
		spun silk	—	F single	20L	9	66,654	80.0	33.2
29	Broadcloth shirting or Poplin	cotton	1.1	W 2-ply	19L, 10R	13, 10	30,677	134.0	75.3
		cotton	1.1	F single	25R	3	46,864	62.0	23.6
30	Bunting	wool	5.1	W 2-ply worsted	11L, 6R	13, 12	8,761	33.0	54.9
		wool	6.9	F worsted	14R	12	10,240	31.5	44.8
31	Burlap, Gunny, Hessian, Hopcloth, Pack cloth, or Sack cloth	jute	5.2	W single	4R	10	1,797	13.1	47.7
		jute	7.0	F single	3R	3	1,651	13.0	51.5
32	Calico	cotton	1.0	W single	22R	15	26,830	69.0	57.6
		cotton	0.7	F single	24R	5	35,146	58.0	41.5
33	Cambric	cotton	1.0	W single	32R	6	36,775	87.0	48.4
		cotton	1.1	F single	26R	6	37,716	81.5	51.6
34	Canvas or Sail cloth	cotton	0.9	W 3-ply	9L, 8R	7, 16	2,494	43.0	49.7
		cotton	0.9	F 3-ply	8L, 5R	9, 12	2,638	29.3	50.3
35	Canvas, cross-stitch, or Penelope canvas	cotton	0.7	W single	24R	3	19,480	26.0	36.0
		cotton	0.9	F single	18R	11	10,895	28.0	62.8
36	Canvas, Dundee	jute	5.5	W single	4R	15	1,697	17.0	48.7
		jute	7.1	F single	4R	7	1,016	18.0	50.5
37	Canvas, needlepoint, or Berlin canvas	cotton	0.6	W 5-ply	9L, 16R	7, 10	3,917	24.0	56.3
		cotton	0.6	F 4-ply	11L, 12R	6, 11	4,728	25.0	43.8
38	Cartridge cloth	spun silk	—	W single	11L	8	6,518	29.0	47.1
		spun silk	—	F single	11L	7	6,096	80.0	52.8

TABLE 1. (Continued) *Analysis of textiles*

	Fabric											
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet	Dry	Wet
								Res.	Dev.	Res.		
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
18	3.37	0.0101	32.0	dyed	1.4	0.2	—	21	4	110	0	—
							—	27	6	85	17	294
19	0.84	0.0069	51.5	dyed, coated with regenerated cellulose	39.0	1.0	—	12	8	—	0	—
							—	6	19	—	0	—
20	36.12	0.0511	36.0		4.3	67.6	—	128	9	100	22	159
							—	51	9	100	8	213
21	10.93	0.0409	50.0 tubular		2.3	0.8	5.1	109	7	134	22	205
							3.8	109	6	137	22	191
22	10.75	0.0160	45.0	mercerized, coated	—	12.9	—	138	5	48	0	—
							—	115	6	94	22	114
23	1.49	0.0039	38.3	bleached	0.6	0.5	0.7	23	7	187	0	—
							2.6	16	4	138	5	440
24	2.74	0.0085	35.5	bleached	1.4	0.2	—	21	2	105	17	324
							—	14	8	100	27	278
25	3.59	0.0072	39.5	dyed, moiré	2.1	0.2	—	86	5	89	15	293
							—	31	5	74	17	394
26	5.67	0.0183	73.0	napped	3.5	1.0	9.4	85	7	118	8	155
							0.0	17	13	226	17	100
27	17.35	0.0394	36.4	flame-resistant	26.2	13.0	0.3	69	7	103	0	—
							+3.9	111	9	99	5	200
28	2.26	0.0060	32.0	bleached bleached, dyed	6.2	0.6	—	61	10	67	17	200
							—	33	6	73	17	200
29	3.84	0.0056	35.0	bleached, mercerized	1.0	0.3	3.6	88	6	122	5	340
							+3.4	18	2	156	11	200
30	4.30	0.0181	19.3	bleached	1.8	0.1	—	47	3	81	38	200
							—	38	8	87	44	175
31	9.06	0.0253	35.8		2.3	0.9	+6.0	80	5	93	0	—
							+4.2	109	11	87	0	—
32	2.67	0.0086	25.0	dyed	0.5	0.1	1.9	28	10	157	11	100
							+1.0	21	10	119	33	100
33	2.79	0.0057	36.5	bleached	0.6	0.2	2.0	37	14	119	5	220
							0.6	28	12	114	11	227
34	17.67	0.0260	32.7		1.9	0.7	5.4	297	1	—	33	—
							1.3	219	5	124	11	73
35	2.45	0.0125	27.0	bleached, dyed, sized	30.2	0.4	2.3	17	5	53	5	160
							1.1	33	10	73	5	320
36	11.16	0.0215	87.3		2.5	1.0	2.6	121	8	113	7	143
							1.9	134	6	117	7	143
37	6.95	0.0281	26.5	dyed, sized	13.4	0.2	1.7	86	3	99	22	150
							3.6	79	4	91	5	1340
38	5.52	0.0187	49.0	dyed	2.2	0.1	—	57	3	61	50	32
							—	11	9	60	80	80

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Fiber Length inch	Yarn Construction	Yarn Twist no. per in., direction	Yarn Twist Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
39	Challis	wool	2.5	W worsted	14R	11	28,182	62.0	60.2
		wool	3.0	F worsted	15R	7	32,836	53.0	39.4
40	Cheesecloth, Surgical gauze, or Tobacco cloth	cotton	1.0	W single	30R	6	26,292	31.4	57.5
		cotton	1.0	F single	38R	7	33,004	27.7	41.0
41	Chiffon	silk	continuous	W single	33, alternately L, R	4	181,944	106.0	47.8
		silk	continuous	F single	34, alternately L, R	6	166,908	102.0	50.8
42	China grass cloth	ramie	4.4	W sliver	0	—	28,804	65.0	60.6
		ramie	2.1	F sliver	0	—	54,382	71.0	37.5
43	China silk	silk	continuous	W single	0	—	252,000	148.0	51.2
		silk	continuous	F single	0	—	260,400	112.0	49.6
44	Chintz	cotton	0.5	W single	21R	—	17,640	66.6	49.8
		cotton	0.5	F single	20R	—	19,320	64.0	50.1
45	Chintz, glazed	cotton	0.9	W single	21R	13	18,564	75.0	50.2
		cotton	1.0	F single	19R	10	19,572	63.0	49.9
46	Chintz, water-resistant	cotton	0.9	W single	16R	4	18,858	67.0	—
		cotton	1.0	F single	21R	15	12,172	61.0	—
47	Côteline	wool	2.2, 1.3	W 4-ply ratiné	15R, 9R, 15L, 5R, 7R	13, 14, 10, 24, 19	3,847	12.0	23.4
		wool	1.4	W woolen	11L	5	3,049	12.0	31.9
		wool	2.3, 1.3	F 4-ply ratiné	15R, 8R, 13L, 8R, 7R	11, 23, 6, 11, 19	3,864	10.0	20.6
		wool	1.3	F woolen	10L	13	3,150	10.0	23.8
48	Crêpe, Canton silk	silk	continuous	W single	0	—	88,941	200.0	55.3
		silk	continuous	F single	36, alternately 2L, 2R	14	52,439	96.5	45.7
49	Crêpe, Canton wool	wool	3.3	W worsted	11L	18	18,346	72.0	61.2
		wool	1.4	F worsted	28, alternately 2L, 2R	13	18,362	46.0	38.2
50	Crêpe, cellulose acetate rayon and silk	cellulose acetate rayon	continuous	W multifilament	0	—	45,646	133.3	77.4
		silk	continuous	F single	45L	10	139,264	89.0	22.6
51	Crêpe de Chine	silk	continuous	W single	0	—	75,180	116.9	44.1
		silk	continuous	F single	35, alternately 2L, 2R	2	64,512	92.6	56.7
52	Crêpe, flat	silk	continuous	W single	0	—	78,431	216.0	62.6
		silk	continuous	F single	58, alternately 2L, 2R	9	51,904	86.0	37.1
53	Crêpe Georgette or Crêpe Elizabeth	silk	continuous	W single	46, alternately 2L, 2R	3	150,024	106.0	53.1
		silk	continuous	F single	47, alternately ·	5	137,256	93.0	46.5
					nately 2L, 2R				
54	Crêpe, Japanese	cotton	0.8	W single	17R	15	28,711	64.0	43.4
		cotton	0.7	F single	23, alternately 2L, 2R	10	15,414	41.0	56.3
55	Crêpe plissé	cotton	1.2	W single	20R	9	45,721	99.0	64.3
		cotton	1.2	F single	22R	11	74,290	87.0	37.2
56	Crêpe, regenerated cellulose rayon	regenerated cellulose	continuous	W multifilament	8L	23	42,958	120.0	60.3
		regenerated cellulose	continuous	F multifilament	14, alternately 2L, 2R	9	36,834	74.0	38.5

TABLE 1. (Continued) *Analysis of textiles*

					Fabric							
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet	Dry	Wet
								Res.	Dev.	Res.		
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
39	2.67	0.0083	27.0	printed	0.6	0.5	—	24	5	92	22	255
							—	14	8	114	27	207
40	1.14	0.0077	36.0	bleached	0.4	0.1	1.6	14	7	114	0	—
							2.2	5	22	180	8	137
41	0.66	0.0033	39.0	printed	2.2	0.2	—	15	13	113	15	147
							—	16	7	106	12	250
42	2.50	0.0050	33.3	bleached	0.6	1.3	0.0	40	18	118	0	—
							0.0	39	29	90	0	—
43	0.46	0.0018	36.5	dyed	5.1	0.4	—	7	14	143	2	550
							—	6	7	83	2	450
44	4.20	0.0067	34.9	printed	4.1	0.1	2.1	43	—	109	—	—
							7.5	40	—	113	—	—
45	4.55	0.0062	35.7	printed, calendered	5.1	0.2	3.1	43	5	107	6	133
							0.0	39	5	121	33	48
46	5.77	0.0097	35.6	printed, coated	4.5	0.3	—	57	2	116	11	82
							—	54	6	107	15	80
47	7.44	0.0297	56.0	dyed	3.4	0.4	—	24	3	83	33	170
							—	16	4	100	33	170
48	1.86	0.0055	70.0	dyed	1.0	0.1	—	57	7	82	33	152
							—	46	4	74	33	176
49	3.88	0.0123	39.0	bleached	1.6	0.1	—	44	2	68	33	227
							—	23	6	74	60	195
50	2.21	0.0069	38.0	bleached	0.7	0.3	—	23	10	70	40	125
							—	25	6	76	44	91
51	2.12	0.0058	33.7		—	0.4	—	54	7	74	22	109
							—	43	6	67	31	100
52	2.90	0.0061	39.0	bleached, weighted	6.4	36.0	—	61	4	90	17	265
							—	41	6	88	27	185
53	0.73	0.0047	40.5	bleached, sized	11.8	0.7	—	16	6	88	17	294
							—	15	3	87	25	200
54	3.40	0.0141	29.0	dyed	1.8	0.1	0.5	26	11	150	17	147
							0.0	28	4	114	25	176
55	2.09	0.0070	34.5	bleached, crêped	0.8	0.3	0.0	17	4	153	22	100
							+0.3	16	6	119	35	126
56	3.11	0.0080	37.0	bleached	1.4	0.7	7.5	43	3	33	33	133
							2.4	27	3	30	50	66

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Fiber Length inch	Yarn Construction	Yarn Twist no. per in., direction	Yarn Twist Deviation pctg.	Yarn Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
57	Crêpe Roshanara	silk	continuous	W single	0	—	145,040	236.0	24.9
		wool	1.7	F 2-ply worsted	29, alternately 4L, 4R	6	6,350	30.0	75.0
58	Crêpe serpentine	cotton	1.1	W single	13R	15	31,248	73.0	41.5
		cotton	0.8	F single	37R	9	18,396	41.0	58.0
59	Cretonne	cotton	0.9	W 2-ply	21L, 14R	13, 6	14,305	62.0	50.6
		cotton	0.9	F single	11L	6	10,492	47.0	49.2
60	Crinoline	cotton	0.9	W single	24R	4	19,060	45.3	53.9
		cotton	1.0	F single	18R	5	19,698	38.2	45.5
61	Crinoline hair cloth	cotton	1.0	W 2-ply	18L, 17R	6, 2	11,054	56.0	66.9
		horse hair	continuous	F fiber	0	—	11,668	29.0	33.3
62	Dress linen	linen	2.1	W single	10R	8	14,028	48.7	56.7
		linen	1.6	F single	16R	18	15,624	48.2	43.2
63	Duck, tent	cotton	1.0	W 2-ply	12L, 10R	9, 14	7,216	56.0	57.5
		cotton	0.9	F 2-ply	10L, 14R	17, 8	9,761	54.0	42.5
64	Épingle	wool	2.8	W worsted	16L	6	17,816	68.0	52.6
		wool	2.4	F worsted	6R	10	10,878	38.5	46.8
65	Éponge	wool	1.9	W 4-ply gimp	7R, 16R, 18L, 4R, 12L, 2R	10, 29, 9, 8, 16, 20	2,227	14.0	48.9
		wool	2.9	F 4-ply gimp	8R, 15R, 23L, 16R, 3L, 2R	9, 12, 10, 23, 23, 15	2,174	13.0	50.6
66	Étamine	wool	3.6	W twist on twist	19L, 11L	7, 12	7,678	32.0	52.5
		wool	3.0	F twist on twist	17L, 10L	12, 11	7,501	28.0	47.3
67	Fabrikoid	cotton	0.9	W single	19R	4	19,396	66.0	26.0
		cotton	1.0	F single	16R	5	27,191	52.0	19.7
68	Facing cloth	wool	1.3	W woolen	14L	7	5,305	64.0	59.1
		wool	1.6	F woolen	13R	2	6,930	52.0	39.1
69	Felt, punched	jute	2.5	W single	5R	16	1,758	9.0	12.2
		jute	2.4	F single	3R	17	2,907	9.0	10.0
70	Flannel, baby	wool	2.0	W woolen	16L	7	11,651	35.5	51.9
		wool	2.9	F woolen	9L	12	9,752	36.0	47.0
71	Flaxon, India linon, of Persian lawn	cotton	1.0	W single	35R	1	72,836	114.0	56.5
		cotton	0.9	F single	16R	4	93,156	107.0	42.8
72	Flexible net	cotton	0.9	W 2-ply	14L, 19R	10, 7	5,142	24.0	49.9
		cotton	1.0	F 2-ply	16L, 21R	10, 7	4,881	22.0	50.1
73	Gingham, chambray	cotton	0.7	W single	19R	11	14,028	69.0	70.4
		cotton	0.9	F single	25R	10	25,343	54.0	29.3
74	Green cloth	cotton	1.1	W single	22R	2	11,970	72.0	44.6
		cotton	1.0	F single	31R	4	23,940	68.0	36.8
75	Gros grain	silk	continuous	W single	10L	9	97,104	216.0	38.7
		silk	continuous	F single	0	—	52,710	52.0	60.6
76	Habutae	silk	continuous	W single	0	—	154,812	124.0	40.0
		silk	continuous	F single	0	—	88,788	103.4	60.0
77	Handkerchief linen or Linen sheer	linen	1.8	W single	19R	5	61,942	100.0	54.5
		linen	1.8	F single	25R	1	61,849	83.0	43.9
78	Holland, window, or Shade cloth	cotton	—	W single	—	—	—	54.0	—
		cotton	—	F single	—	—	—	50.0	—
79	Homespun	wool	4.3	W woolen	17R	11	3,351	22.3	52.7
		wool	4.7	F woolen	19R	12	2,976	18.4	47.5
80	Hose jacket	cotton	1.0	W 12-ply	1L, 10R	0, 12	510	29.0	60.4
		cotton	0.9	F 45-ply	3L, 7R	0, 17	142	7.0	39.7

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation at breaking load Dry pctg.	Wet pctg. of dry
57	4.59	0.0155	39.0	dyed	1.5	0.1	—	49	9	112	17	294
							—	40	4	50	67	175
58	3.42	0.0109	30.0	printed, crêped	1.2	0.4	0.8	30	9	140	11	155
							+7.3	22	7	114	80	125
59	5.61	0.0135	29.8	printed	0.9	0.7	3.4	64	4	117	5	440
				dyed			+0.6	63	9	154	17	100
60	2.55	0.0120	26.5	sized	30.0	0.1	2.2	38	9	74	5	320
							0.2	23	8	87	17	100
61	4.68	0.0183	22.3	bleached	3.3	1.5	—	75	4	115	17	147
							—	53	3	91	33	152
62	4.87	0.0085	78.6		4.3	1.5	5.4	74	6	258	17	—
							7.1	50	10	280	—	—
63	8.91	0.0180	33.8	dyed	1.3	0.5	2.1	149	3	107	22	195
							1.2	101	9	138	17	100
64	4.31	0.0101	36.0	dyed	0.8	0.1	—	46	3	72	25	220
							—	22	10	105	17	394
65	8.02	0.0310	55.0	dyed	1.8	0.1	—	21	—	86	30	223
							—	19	5	84	44	177
66	4.80	0.0174	56.0	dyed	0.9	0.1	—	39	4	69	33	203
							—	31	5	65	44	152
67	7.68	0.0107	40.3	coated, dyed, embossed	2.2	18.2	—	61	5	102	0	—
							—	53	3	113	50	70
68	10.49	0.0264	56.0	dyed, napped	0.5	0.1	—	52	3	77	22	150
							—	38	4	71	50	100
69	31.69	0.1382	31.3	84 percent hair filling	—	3.8	—	31	14	68	0	—
							—	31	21	52	0	—
70	3.96	0.0133	27.0	napped	1.3	0.1	—	13	7	108	22	300
							—	11	2	118	22	300
71	1.64	0.0046	39.5	bleached, sized	1.4	0.1	0.8	25	12	156	5	220
							2.8	19	5	121	5	340
72	5.24	0.0183	21.1	bleached, sized	43.9	0.2	6.1	59	4	70	33	33
							5.4	46	2	80	33	48
73	4.08	0.0097	28.8	dyed	5.0	0.6	3.7	45	3	129	12	183
				bleached			1.9	25	10	148	12	183
74	5.19	0.0104	38.5	dyed, coated	44.6	3.9	—	56	9	70	11	100
							—	44	5	55	11	200
75	3.61	0.0078	34.0	weighted, dyed	5.5	15.9	—	46	4	83	17	259
							—	62	2	84	17	177
76	1.14	0.0029	36.5	bleached	1.0	0.6	—	33	6	94	22	150
							—	49	20	71	17	171
77	1.61	0.0045	36.0	bleached	0.8	0.1	—	28	13	178	5	—
							—	21	8	167	5	160
78	6.15	0.0084	46.5	filled	5.8	52.7	—	58	5	53	5	—
							—	50	2	48	7	157
79	7.58	0.0249	28.7		1.9	0.5	—	65	4	95	33	203
							—	49	5	104	30	250
80	7.00	0.1169	8.5 tubular		2.2	0.5	—	>300	—	—	—	—
							—	>300	—	—	—	—

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber		Yarn					
		Classification	Length	Construction	Twist		Count	No. per in. of fabric	Pctg. of fabric
					no. per in., direction	Deviation pctg.	yds. per lb.		
			inch						
81	Indianhead, Beachcloth, Butcher's linen, or Crash	cotton	0.9	W single	15R	9	11,592	52.0	51.7
		cotton	0.9	F single	12R	13	11,088	44.0	49.0
82	Jusi	silk in the gum	continuous	W single	0	—	210,000	88.0	60.2
		silk in the gum	continuous	F single	0	—	123,648	84.0	39.8
83	Linolean	linen	—	W single	—	—	11,844	32.0	46.4
		linen	—	F single	—	—	11,424	29.0	54.0
84	Metal cloth	silk	continuous	W single	0	—	162,918	57.0	5.6
		copper, cotton (30.6 %)	continuous, 1.2	F lamé	72R, 12L, 7R	5, 15, 30	15,792	99.0	94.6
85	Metalline	silk in the gum	continuous	W single	0	—	213,360	81.0	20.5
		regenerated cellulose	continuous	F multi-filament	0	—	28,980	42.0	79.8
86	Moiré	cellulose acetate rayon	continuous	W multi-filament	0	—	62,496	154.0	40.9
		cellulose acetate rayon	continuous	F multi-filament	25L	2	13,003	53.0	59.2
87	Mull	cotton	1.0	W single	18R	8	42,286	99.5	84.0
		silk	continuous	F single	0	—	273,268	98.0	15.2
88	Muslin, embossed	cotton	0.9	W single	21R	2	18,127	44.0	44.8
		cotton	0.9	F single	19R	4	16,733	41.0	48.0
89	Nainsook or Masalia cloth	cotton	1.1	W single	19R	5	45,746	88.0	64.5
		cotton	1.1	F single	18R	4	31,178	78.0	35.8
90	Nankin	cotton	0.9	W single	21R	4	17,959	82.0	61.6
		cotton	1.0	F single	20R	6	26,216	75.0	38.2
91	Ninon	cellulose acetate rayon	continuous	W multi-filament	27L	16	82,130	105.0	50.2
		cellulose acetate rayon	continuous	F multi-filament	29L	8	78,079	96.0	49.2
92	Nurses' cloth	cotton	1.0	W single	25R	4	23,713	91.3	56.8
		cotton	1.0	F single	29R	5	30,542	89.4	44.5
93	Oil cloth	cotton	0.9	W single	22R	4	15,581	44.0	—
		cotton	0.9	F single	19R	5	20,110	39.0	—
94	Organdie	cotton	—	W single	—R	—	61,471	85.0	60.1
		cotton	—	F single	—R	—	75,222	68.0	39.8
95	Osnaburg	cotton	0.9	W single	16R	18	6,668	39.0	47.9
		cotton	1.0	F single	14R	7	4,003	31.0	50.2
96	Ottoman	silk	continuous	W single	0	—	64,957	140.0	22.7
		silk	continuous	F single	18L	6	80,346	20.0	2.5
		wool	0.8	F 3-ply worsted	11R, 27R	5, 3	3,112	20.0	74.9
97	Percaline	cotton	1.0	W single	34R	2	49,308	106.0	59.1
		cotton	1.0	F single	30R	3	72,912	96.0	41.4
98	Pongee	wild silk	continuous	W single	6L	0	56,700	75.0	—
		wild silk	continuous	F single	0	—	55,463	75.0	—

TABLE 1. (Continued) *Analysis of textiles*

				Fabric								
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet	Dry	Wet
								Res.	Dev.	Res.		
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
81	5.25	0.0108	36.0	bleached, permanent-finished	0.0	0.0	3.0	51	9	94	12	—
							2.3	56	6	100	—	—
82	0.62	0.0038	17.0	dyed	13.0	1.3	—	13	10	85	11	209
							—	13	24	100	11	200
83	3.24	0.0105	36.5	dyed, sized	10.2	0.2	0.3	49	5	45	11	—
							1.0	31	16	68	11	—
84	3.66	0.0054	19.9	dyed	2.8	83.4	—	7	3	100	11	300
							—	46	11	117	5	—
85	1.07	0.0050	36.0	bleached	2.6	0.1	—	12	5	58	16	206
				dyed			—	22	3	32	33	100
86	4.01	0.0083	39.8	dyed, moiré	0.5	0.1	8.3	27	5	81	16	206
							0.4	59	4	54	50	88
87	1.55	0.0042	34.8	bleached	1.2	0.1	1.1	21	5	205	0	—
							7.8	13	12	77	15	220
88	3.18	0.0057	26.5	bleached, loaded, embossed	7.7	19.3	0.0	23	9	104	11	100
							0.0	22	5	100	17	129
89	1.67	0.0042	34.0	bleached	0.4	0.2	0.9	20	4	140	0	—
							3.9	10	10	130	5	340
90	4.62	0.0079	36.3	bleached	7.2	0.9	3.5	71	7	124	17	177
				dyed			0.8	48	4	123	17	100
91	1.49	0.0051	37.6	dyed	0.6	0.2	1.0	15	5	80	7	157
							0.0	18	6	56	4	275
92	4.04	0.0096	35.5	bleached	1.9	0.1	1.4	50	6	128	5	220
							0.5	49	6	112	22	191
93	10.46	0.0142	43.0	coated	2.2	43.4	—	48	3	77	5	140
							—	37	0	92	12	92
94	1.34	0.0047	45.5	bleached, permanent-finished	0.0	0.1	0.3	23	8	161	0	—
							1.3	16	5	106	5	220
95	8.32	0.0247	30.3		5.9	1.3	7.5	67	6	121	22	182
							0.5	73	5	129	17	177
96	5.55	0.0179	39.0	dyed	2.7	0.5	—	71	2	75	22	227
							—	56	4	55	66	135
97	2.08	0.0038	37.5	dyed, calendered	4.6	0.1	0.7	24	8	150	0	—
							4.6	16	6	100	16	312
98	1.76	0.0050	33.0	sized	8.7	1.7	—	47	3	72	31	119
							—	46	6	76	32	116

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Classifica-tion	Length inch	Construc-tion	Twist no. per in., direction	Devia-tion pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
		Fiber		Yarn					
99	Poplin	silk	continuous	W single	0	—	128,688	228.0	19.3
		wool	1.2	F 3-ply	33L, 13L	5, 8	7,316	43.5	80.9
100	Radium, cellulose acetate rayon	cellulose acetate rayon	continuous	W multi-filament	0	—	47,259	189.0	72.4
		cellulose acetate rayon	continuous	F multi-filament	0	—	49,383	71.6	28.2
101	Radium, silk	silk	continuous	W single	0	—	90,719	164.3	69.8
		silk	continuous	F single	26L	5	130,344	99.8	31.3
102	Radium, silk in the gum	silk in the gum	continuous	W single	0	—	68,729	164.0	69.6
		silk in the gum	continuous	F single	27L	3	103,093	97.0	30.1
103	Radium, weighted silk, or Pussy willow taffeta	silk	continuous	W single	0	—	58,480	165.0	69.7
		silk	continuous	F single	27L	5	76,931	95.0	30.3
104	Rajah	spun silk	—	W 2-ply	18L, 16R	7.5	48,972	136.0	54.3
		silk	continuous	F single	0	—	38,724	63.0	45.7
105	Ratiné or Sponge cloth	cotton	1.2	W 5-ply gimp	14L, 17R, 16R, 16R, 3R	9, 12, 16, 12, 10	5,178	25.0	51.7
		cotton	1.2	F 5-ply gimp	14L, 19R, 20R, 16R, 3R	4, 12, 8, 14, 10	4,136	20.5	48.5
106	Rep	cotton	0.9	W 2-ply	11L, 12R	5, 10	5,588	72.0	85.4
		cotton	0.9	F 2-ply	10L, 11R	7, 7	6,878	16.0	14.9
107	Rhea cloth	ramie	3.7	W single	11R	14	2,700	46.0	55.6
		ramie	3.8	F single	12R	14	3,030	36.0	43.0
108	Shantung	wild silk	continuous	W single	0	—	27,997	75.8	31.2
		wild silk	continuous	F single	0	—	5,663	42.9	67.0
109	Sheeting, bleached light-weight, or Muslin	cotton	0.9	W single	23R	10	23,856	91.8	58.1
		cotton	0.9	F single	16R	13	36,288	84.0	41.0
110	Sheeting, bleached medium-weight, or Muslin	cotton	0.8	W single	20R	3	17,892	73.0	56.4
		cotton	0.6	F single	15R	7	21,420	66.0	42.5
111	Sheeting, bleached heavy-weight, or Muslin	cotton	0.9	W single	18R	12	16,632	78.3	50.6
		cotton	0.9	F single	14R	12	18,228	74.0	49.2
112	Sheeting, linen	linen	1.4	W single	9R	20	14,580	64.4	52.3
		linen	1.8	F single	6R	16	15,030	60.0	47.6
113	Sheeting, percale	cotton	0.9	W single	24R	9	32,088	109.0	53.4
		cotton	0.9	F single	21R	9	35,616	98.0	46.5
114	Sheeting, un-bleached light-weight, or Muslin	cotton	0.9	W single	17R	12	14,784	59.0	60.5
		cotton	1.0	F single	13R	10	19,824	51.0	39.1
115	Sheeting, un-bleached medium-weight, or Muslin	cotton	0.9	W single	19R	6	15,036	67.0	58.2
		cotton	0.9	F single	13R	11	21,336	60.0	41.0
116	Sheeting, un-bleached, heavy-weight, or Muslin	cotton	0.9	W single	18R	5	15,876	71.0	53.5
		cotton	0.8	F single	12R	7	18,732	71.0	46.7
117	Sheeting, rubber	cotton	—	W single	—	—	—	60.5	—
		cotton	—	F single	—	—	—	59.0	—
118	Sheeting, stork	cotton	—	W single	—	—	—	99.0	—
		cotton	—	F single	—	—	—	78.0	—

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation Dry pctg.	Elongation Wet pctg. of dry
99	4.58	0.0121	40.0	bleached	2.7	0.1	—	51	2	98	17	353
							—	54	2	52	50	184
100	2.51	0.0054	41.0	bleached	0.9	0.2	0.9	50	4	54	22	235
							0.8	19	14	58	17	150
101	1.61	0.0051	38.8		1.8	2.2	—	63	2	92	25	148
							—	38	5	79	18	161
102	1.99	0.0055	39.0		—	1.2	—	87	5	86	24	158
							—	44	2	93	18	183
103	2.41	0.0046	39.0	weighted, bleached	11.2	36.8	—	64	4	80	15	187
							—	38	3	82	16	194
104	2.94	0.0097	31.3	dyed	1.6	0.2	—	69	16	80	50	50
							—	54	4	83	50	50
105	6.71	0.0223	36.3	bleached	6.8	1.0	2.0	25	14	108	17	100
							0.0	27	11	85	33	67
106	9.22	0.0240	49.2	dyed	0.6	0.2	0.6	212	6	112	11	155
							0.3	41	7	105	5	220
107	6.66	0.0122	44.5		0.5	0.2	3.1	106	9	125	8	38
							0.0	91	9	126	17	100
108	6.79	0.0135	27.4	weighted	3.1	32.6	—	103	2	67	50	134
							—	172	6	68	35	114
109	3.55	0.0081	90.0	bleached	0.4	0.1	3.1	53	4	106	8	163
							2.1	39	3	85	13	154
110	3.98	0.0092	65.0	bleached	1.1	0.1	5.5	57	8	102	11	100
							+2.1	40	7	103	20	125
111	4.96	0.0093	72.0	bleached	1.8	0.8	4.7	67	4	104	11	118
							2.1	69	4	119	13	154
112	4.93	0.0073	70.5	bleached	0.9	0.2	3.1	91	10	100	8	125
							2.1	86	7	87	11	91
113	3.58	0.0061	81.5	bleached, mercerized	0.5	0.2	5.5	60	7	92	25	108
							3.1	55	4	109	8	213
114	3.62	0.0114	75.5		7.8	1.0	9.4	46	5	113	13	153
							10.4	36	4	111	11	182
115	4.44	0.0112	82.0		6.8	1.0	8.6	55	8	118	17	153
							6.3	46	6	139	13	131
116	4.96	0.0116	81.5		4.0	1.2	6.3	61	5	136	17	171
							7.3	69	4	126	11	191
117	15.22	0.0127	36.7	coated	—	58.6	—	54	5	67	0	—
							—	52	5	81	33	61
118	3.58	0.0062	35.3	coated	5.4	3.6	—	31	11	55	5	—
							—	15	5	47	22	100

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg of fabric
119	Shirred fabric or	cotton	1.1	W 2-ply	25L, 13R	8, 4	16,422	46.0	17.
	Suspender webbing	cotton, rubber	1.1 continuous	W 7-ply cable	80L, 6R, 30R, 25L, 13R	10, 20, 5, 8, 4	622	6.0	40.
		cotton	0.9	F 2-ply	8L, 11R	5, 6	9,122	86.0	41.
120	Sign cloth	cotton	0.9	W single	18R	10	21,168	60.6	48.
		cotton	0.9	F single	22R	13	26,628	53.0	39.
121	Silkaleen or	cotton	1.1	W single	30R	3	52,466	71.6	58
	Near silk	cotton	1.1	F single	30R	1	60,413	57.8	41
122	Soisette	cotton	1.3	W single	22R	3	66,444	75.0	27
		cotton	1.0	F single	4R	7	34,944	96.0	72
123	Swiss, composition dot	cotton	1.2	W single	32R	3	46,754	64.0	—
		cotton	0.9	F single	28R	6	47,040	47.0	—
124	Taffeta	silk	continuous	W single	36L	5	18,050	248.3	50
		silk	continuous	F single	0	—	7,280	93.0	48
125	Tarlatan or	cotton	0.9	W single	20R	5	30,156	20.9	53
	Crown lining	cotton	0.7	F single	23R	4	35,574	18.7	46
126	Theatrical gauze	linen	1.3	W single	11R	7	8,278	21.0	59
		linen	1.8	F single	8R	13	11,231	19.9	40
127	Tire builder or	cotton	1.1	W 8-ply	4L, 13R	7, 7	1,720	54.0	52
	Chafer fabric	cotton	1.1	F 8-ply	4L, 11R	3, 13	1,852	23.0	47
128	Tire cord fabric	cotton	1.1	W 15-ply hawser	8L, 9R, 19R	4, 12, 4	969	20.0	98
		cotton	1.1	F single	16R	11	14,994	8.5	1
129	Tire flipper fabric	cotton	1.0	W 2-ply	8L, 11R	13, 5	5,432	38.0	49
		cotton	0.9	F 2-ply	11L, 11R	7, 5	5,313	37.0	50
130	Toweling, cotton and linen crash	cotton	1.2	W 2-ply	14L, 7R	6, 13	8,870	40.0	39
		linen	2.6	F single	6R	18	3,671	23.4	60
131	Toweling, glass, Glass-check, or Glass cloth	linen	1.9	W single	9R	10	8,963	39.0	58
		linen	1.8	F single	9R	11	10,592	32.0	43
132	Toweling, hemp crash	hemp	2.8	W single	8R	10	5,090	39.0	52
		hemp	3.0	F single	7R	10	4,536	32.0	47
133	Tracing cloth	linen	1.0	W single	31R	4	55,793	91.0	50
		linen	1.2	F single	20R	3	54,936	86.0	50
134	Tropical worsted	wool	3.0	W 2-ply worsted	15L, 6R	6, 18	9,786	52.0	51
		wool	3.1	F worsted	11R	9	8,921	45.0	48
135	Turkoman, Chenille cloth, or Sham plush	cotton	1.1	W 2-ply	13L, 13R	10, 6	13,171	43.0	15
		cotton	0.9	F 3-ply chenille	18R	8	947	15.0	84
136	Umbrella cloth, cotton and silk	silk	continuous	W single	0	—	55,440	128.0	84
		cotton	1.3	F single	12R	3	29,333	104.0	91
137	Umbrella cloth, silk	silk	continuous	W single	13L	6	120,960	180.0	50
		silk	continuous	F single	0	—	67,502	112.0	43
138	Vellum	cotton	1.0	W single	12R	5	16,380	52.0	43
		cotton	1.0	F single	12R	8	13,633	52.0	53
139	Visca fabric	regenerated cellulose	continuous	W 4-ply	0	—	6,894	35.0	53
		regenerated cellulose	continuous	F 4-ply	8R, 4L	5, 25	7,361	29.0	47
140	Voile	cotton	1.1	W single	28R	3	42,118	61.0	56
		cotton	1.0	F single	44R	13	36,347	55.7	56
141	Voile, rice	cotton	1.1	W single	25R	32	43,932	61.0	84
		cotton	1.3	flake yarn	40R, 35R	17, 5	15,708	36.0	68

TABLE 1. (Continued) *Analysis of textiles*

				Fabric								
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet	Dry	Wet
								Res.	Dev.	Res.		
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	Pctg.	pctg. of dry
119	15.70	0.0506	1.6	bleached bleached	4.5	0.5	—	—	—	—	—	—
120	3.27	0.0068	54.0	mercerized, dyed bleached, loaded	25.8	16.1	— 3.9 7.3	— 27 21	— 8 5	— 81 76	— 8 17	138 76
121	1.38	0.0036	35.7	bleached, calendered	0.0	0.1	0.9 1.3	17 9	4 4	159 178	0 5	— 440
122	2.36	0.0066	31.5	mercerized, dyed	0.4	0.2	0.3 3.0	21 38	8 4	90 113	0 16	— 138
123	1.91	0.0069	37.4	bleached, printed	1.7	9.5	0.6 0.9	13 7	7 13	123 157	8 22	100 100
124	1.47	0.0045	36.2	weighted, dyed	4.1	26.2 1.1	— —	41 33	4 5	— —	22 6	— —
125	0.67	0.0063	59.0	sized	22.1	0.7	1.7 0.3	8 6	16 22	50 50	0 0	— —
126	2.27	0.0125	36.5		3.5	0.9	0.5 0.6	26 26	2 2	119 108	0 0	— —
127	14.80	0.0371	—		4.2	0.9	— —	246 237	2 6	— —	30 22	— —
128	13.19	0.0372	—		3.0	0.2	— —	274 1	5 0	— —	33 0	— —
129	7.91	0.0205	—		3.4	1.0	— —	102 123	8 5	— —	15 11	— —
130	6.84	0.0188	19.0	bleached	0.7	0.4	3.6 +9.6	70 76	6 4	113 146	7 33	229 48
131	4.12	0.0066	15.8	bleached, dyed, calendered	1.2	0.4	0.5 0.0	37 24	7 5	168 196	3 6	367 183
132	8.80	0.0130	18.0	bleached	1.8	0.5	5.4 0.0	120 92	6 8	148 149	17 17	147 294
133	3.16	0.0031	37.5	coated	31.2	0.8	— —	50 40	5 5	— —	0 11	— —
134	6.03	0.0138	59.0	dyed	0.9	1.0	— —	63 53	4 3	72 81	33 33	182 200
135	12.20	0.0389	51.9	dyed	0.9	0.4	4.0 1.5	51 18	5 6	108 144	17 12	129 183
136	2.44	0.0048	21.9	dyed, water-resistant	2.1	1.2	— —	15 54	2 5	67 107	33 8	152 138
137	1.74	0.0037	22.0	dyed, water-resistant	5.1	26.3	— —	43 36	1 8	93 89	22 16	150 138
138	4.60	0.0056	40.3	dyed, coated	24.2	18.3	— —	55 45	6 5	44 60	0 50	— 50
139	5.61	0.0202	16.8	dyed	2.0	0.3	10.8 +6.8	75 51	5 9	36 29	25 33	224 100
140	1.62	0.0064	38.0	bleached	2.5	0.2	1.3 8.5	18 15	7 3	144 147	0 5	— 440
141	2.15	0.0105	35.0	bleached, printed	0.6	0.2	4.3 7.8	19 10	1 8	137 140	5 33	320 303

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber		Yarn					
		Classifica-tion	Length	Construc-tion	Twist		Count	No. per in. of fabric	Pctg. of fabric
					no. per in., direction	Devia-tion pctg.			
			inch				yds. per lb.		
142	Webbing or	jute	7.4	W 2-ply	3L, 2R	7, 20	693	16.0	74.2
	Belting	jute	7.0	F single	3R	10	1,000	9.0	26.3
143	Wigan	cotton	0.9	W single	23R	6	13,675	45.0	54.1
		cotton	0.9	F single	19R	8	15,893	45.0	42.2
	2G. Fabrics of figured plain weaves								
144	Armure (Pl. ID)	cotton	1.3	W 2-ply	23L, 29R	8, 10	35,490	176.0	54.8
		cotton	1.2	F 3-ply	17L, 14R	6, 9	8,509	41.2	45.4
145	Denim, figured	cotton	1.0	W single	18R	7	9,996	75.0	63.6
	(Pl. IE)	cotton	0.9	F single	11R	7	8,232	41.0	36.3
146	Muslin, barred	cotton	1.0	W single	25R	2	26,964	73.0	59.1
	(Pl. IIH)	cotton	0.9	F single	24R	4	37,540	67.0	41.5
	I. Fabrics of simple warp rib weave (Fig. 1 B)								
147	Awning cloth	cotton	0.8	W single	9R	8	10,718	89.0	58.4
		cotton	0.8	F single	8R	7	4,721	30.0	41.6
148	Buckram, art	cotton	—	W single	—R	—	—	88.0	—
		cotton	—	F 2-ply	—L, —R	—	—	26.0	—
149	Duck	cotton	0.7	W single	16R	4	12,197	94.0	62.7
		cotton	0.8	F 2-ply	6L, 17R	17, 5	6,014	27.5	37.3
150	Taffeta, jaspé	cotton	0.8	W single	36R	19	20,286	109.6	71.6
		cotton	0.7	F single	37R	16	21,840	54.4	27.6
151	Tarpaulin	jute	2.5	W single	4R	25	2,089	31.0	73.8
		jute	5.8	F single	4R	15	2,570	14.0	26.1
	2I. Fabrics of simple filling rib weaves								
152	Webbing, elastic,	cotton	1.0	W 2-ply	15L, 10R	11, 2	8,280	13.0	11.1
	or Surgical	cotton,	1.0	W 7-ply	14R, 14L, 15R,	7, 14, 10	71	13.0	44.1
	webbing (Fig.1G)	rubber	continuous	cable	9L, 11R	9, 12			
		cotton	1.0	F 2-ply	8L, 15R	10, 8	8,669	19.0	44.7
	I. Fabrics of fancy warp rib weaves								
153	Agaric (Fig. 1C)	wool	2.6	W worsted	7L	6	2,092	82.0	25.2
		wool	0.8, 5.4	F 2-ply spiral	7L, 33L, 2R	16, 4, 20	3,284	34.0	74.9
154	Crêpe seersucker,	cotton	0.9	Wg single	26R	23	15,641	83.0	59.4
	Crinkle cloth, or	cotton	0.9	Ww single	21R	8	7,728	9.0	14.2
	Ripplette (Fig. 1D)	cotton	0.9	F single	31R	8	39,757	60.0	24.7
155	Dimity, striped	cotton	1.0	W single	35R	3	49,619	124.0	69.4
	(Fig. 1E)	cotton	1.0	F single	29R	19	89,712	74.0	30.0
156	Gros de Londres	silk	continuous	W single	12L	8	123,228	246.0	52.8
	(Fig. 1F)	silk	continuous	F single	0	—	61,412	78.0	47.5
	2I. Fabrics of fancy filling rib weaves								
157	Bedford cord,	cotton	1.1	Wg single	22R	4	25,914	130.0	42.1
	cotton, or	cotton	1.1	Ww 2-ply	17L, 15R	7, 6	13,356	34.0	27.5
	Warp piqué	cotton	0.9	F single	28R	7	38,850	97.0	29.9
	(Fig. I H)								
158	Bedford cord,	wool	3.2	W worsted	13R	6	21,991	89.5	61.2
	wool (Fig. 2)	wool	2.3	F worsted	15R	8	28,357	57.0	37.5
159	Canvas, Java, Aida	cotton	0.8	W 2-ply	16L, 12R	7, 17	7,028	28.4	42.7
	canvas, Fancy oat-	cotton	0.6	F single	10R	9	5,300	28.0	57.3
	meal, Imitation								
	gauze, or Mock								
	leno (Fig. 1J)								
160	Faille (Fig. IK)	silk	continuous	W single	14L	4	126,490	232.0	62.3
		silk	continuous	F single	3L	15	68,040	102.0	37.1
161	Linear zigzag or	cotton	0.8	W 3-ply	9L, 11R	5, 17	3,673	31.0	57.5
	Spider weave	cotton	1.0	F 3-ply	4L, 16R	20, 10	3,935	23.0	42.3
	(Fig. IL)								

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness Pctg.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Breaking strength Dry Dev. pctg.	Breaking strength Wet Res. pctg. of dry	Elongation Dry Pctg.	Elongation Wet pctg. of dry
142	18.73	0.0600	4.3		1.5	0.9	6.3	>300	—	—	—	—
							1.5	135	9	143	11	91
143	3.67	0.0093	34.5	dyed, sized	31.9	1.2	4.0	35	5	86	11	100
							+1.3	19	8	105	12	250
144	6.82	0.0139	54.0	dyed	0.6	0.2	3.5	107	10	107	12	183
							0.1	79	6	117	12	92
145	7.66	0.0241	55.0	dyed	2.4	0.5	5.0	91	5	111	22	150
				bleached			2.2	61	7	111	11	120
146	2.94	0.0073	36.5	bleached	2.1	0.2	1.9	44	2	105	10	80
							1.9	24	8	121	10	170
147	9.86	0.0250	29.7		3.8	0.8	9.4	146	5	116	30	167
							0.9	107	10	121	17	100
148	10.11	0.0133	39.1	dyed, sized	12.9	2.3	—	150	4	78	5	340
							—	129	2	68	16	81
149	7.58	0.0161	35.3	bleached, sized	5.7	0.0	4.4	114	8	112	15	80
							+0.6	62	4	115	17	65
150	4.71	0.0117	47.5	dyed, sized	12.5	1.0	8.1	74	11	134	10	133
							2.5	25	20	132	9	114
151	11.96	0.0320	49.0		2.9	1.0	2.8	201	4	—	0	—
							0.3	93	12	—	0	—
152	23.69	0.0560	5.9	dyed	0.3	0.4	. —	—	—	—	—	—
				bleached								
				dyed			—	—	—	—	—	—
153	9.78	0.0307	56.0	dyed	0.8	0.0	—	43	3	74	40	168
							—	85	3	56	90	167
154	3.64	0.0137	28.3	bleached	0.9	0.1	1.6	23	11	135	7	171
							1.3	21	13	105	17	129
155	1.90	0.0053	35.0	bleached, printed	3.7	1.5	1.1	29	2	166	5	100
							3.8	11	6	118	5	340
156	1.83	0.0040	34.8	weighted, bleached	7.0	28.6	—	66	2	64	17	147
				dyed			—	28	8	86	15	167
157	5.17	0.0171	35.0	bleached	1.0	0.1	1.6	66	2	126	8	138
							1.3	42	5	124	17	194
158	3.81	0.0117	40.5	bleached	1.8	0.4	—	41	3	85	22	255
							—	19	6	89	25	224
159	5.48	0.0265	43.5	dyed, sized	4.3	0.2	5.7	46	3	83	8	138
							3.1	35	4	69	12	92
160	2.33	0.0049	34.3	bleached, weighted	8.5	36.5	—	64	10	78	4	200
							—	23	7	91	2	400
161	8.67	0.0313	—	bleached	0.7	0.1	6.2	94	6	124	11	109
							+5.6	88	8	135	11	155

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber		Yarn					
		Classification	Length	Construction	Twist		Count	No. per in. of fabric	Pctg. of fabric
					no. per in., direction	Deviation pctg.			
			inch				yds. per lb.		
162	Parachute cloth (Fig. 1M)	silk	continuous	W single	0	—	74,248	99.0	45.7
		silk	continuous	F single	0	—	61,022	99.0	54.3
163	Toweling, huck-aback (Fig. 1N)	linen	1.6	W single	11R	6	10,937	77.0	50.1
		linen	1.3	F single	10R	15	11,231	73.0	49.1
	J. Fabrics of simple basket weaves (Fig. 10)								
164	Crêpe Romaine	silk	continuous	W single	50, alternately 2L, 2R	3	83,916	200.0	59.1
		silk	continuous	F single	74, alternately 2L, 2R	14	85,512	155.0	41.4
165	Hardanger cloth	cotton	1.1	W 2-ply	8L, 7R	9, 7	5,477	37.0	49.7
		cotton	1.0	F 2-ply	8L, 4R	4, 12	4,947	32.0	50.4
166	Monk's cloth	cotton, jute	0.9 / —	F 2-ply combination	5L, 7R	18, 20	3,000	20.0	49.1
		cotton, jute	1.0 / —	F 2-ply combination	5L, 7R	14, 17	2,600	20.0	50.8
	2J. Fabrics of fancy basket weaves								
167	Barathea, silk, or Melrose (Fig. 2A)	silk	continuous	W single	14L	8	130,712	323.0	45.4
		regenerated cellulose	continuous	F multi-filament	0	—	3,016	88.0	54.8
168	Barathea, wool, or Twilled matt (Fig. 2B)	wool	3.5	W 2-ply worsted	10L, 5R	11, 18	8,702	74.0	51.0
		wool	3.2	F 2-ply worsted	10L, 3R	12, 13	8,224	66.0	49.1
169	Dimity, barred, or Jaconet (Fig. 2C)	cotton	0.9	W single	26R	2	26,384	73.0	55.2
		cotton	0.8	F single	40R	9	33,701	79.0	44.2
170	Oxford cloth (Fig. 2D)	cotton	1.0	W single	21R	3	8,534	101.0	42.1
		cotton	1.0	F single	11R	6	11,701	51.0	58.0
	2I. Fabrics of oblique rib weaves								
171	Basket cloth (Figs. 2E & 4B)	wool	4.2	W 2-ply worsted	6L, 1R	10, 50	4,582	33.0	58.3
		wool	3.8	F 2-ply worsted	7L, 5R	14, 18	5,429	81.0	46.1
	H. Fabrics of ½ twill weave								
172	Domet, Outing, Shaker, or Tennis flannel, Flannelet, or Gypsy cloth (Fig. 2F)	cotton	0.9	W single	21R	4	25,402	52.0	25.6
		cotton	0.9	F single	10R	10	7,242	48.0	74.3
173	Cashmere (Fig. 2G)	wool	3.2	W worsted	14R	5	27,989	64.0	46.4
		wool	2.3	F worsted	10R	7	32,609	72.0	53.4
174	Flannel, wool (Fig. 2G)	wool	2.9	W woolen	12R	8	17,657	58.0	29.5
		wool	2.1	F woolen	11L	5	5,802	42.0	69.2
175	Henrietta (Fig. 2G)	wool	1.4	W worsted	21R	8	28,157	65.0	45.4
		wool	2.5	F worsted	13R	7	55,969	138.0	53.8
176	Melton, Boxcloth, or Pilot cloth (Fig. 2G)	wool	—	W woolen	—L	—	3,878	40.0	—
		wool	—	F woolen	—R	—	4,603	39.0	—
177	Sacking or Double warp twill (Fig. 2H)	jute	8.2	W single	3R	17	1,323	8.0	72.0
		jute	5.6	F single	4R	33	836	24.0	27.8

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation at breaking load Dry pctg.	Wet pctg. of dry
162	1.64	0.0042	36.5	bleached	4.6	0.4	—	44	1	75	11	100
							—	45	4	96	15	113
163	7.58	0.0114	14.8	bleached	0.6	0.1	1.6	129	6	155	5	—
							0.8	123	5	146	0	—
164	2.37	0.0063	39.5	bleached, weighted	12.2	34.9	—	55	3	75	33	164
							—	39	1	87	22	205
165	7.73	0.0223	39.5	dyed	0.4	0.7	3.6	92	2	105	4	200
							3.1	72	5	97	11	155
166	13.12	0.0388	49.5		1.7	1.0	2.4	96	3	124	11	300
							3.7	110	2	112	11	300
167	3.16	0.0074	24.0	weighted, dyed	4.1	12.4	—	73	7	84	22	159
							—	49	13	49	16	100
168	9.71	0.0245	60.0	dyed	0.7	1.7	—	96	1	89	25	268
							—	94	2	80	45	149
169	2.91	0.0079	35.4	bleached	3.3	0.1	0.6	30	13	157	5	220
							2.2	20	6	135	11	227
170	4.36	0.0099	36.0	bleached, mercerized	4.3	0.1	0.3	38	15	129	0	—
							0.2	49	4	110	8	213
171	7.72	0.0243	57.0	bleached	1.9	1.0	—	78	2	88	25	268
							—	54	5	87	25	232
172	4.68	0.0194	27.5	bleached, napped	0.0	0.1	2.3	35	7	103	5	340
							+1.9	30	14	140	22	100
173	2.99	0.0096	41.0	bleached	2.6	0.4	—	20	4	85	16	419
							—	30	7	67	33	236
174	6.06	0.0174	52.0	bleached, napped	2.0	0.1	—	31	6	71	.17	323
							—	37	4	81	17	388
175	2.93	0.0089	41.5	dyed	3.3	0.9	—	13	3	100	0	—
							—	20	2	65	17	393
176	13.31	0.0401	57.5	dyed, napped	2.4	4.2	—	32	2	84	22	227
							—	35	4	74	35	214
177	16.61	0.0370	30.8		2.3	2.0	4.3	181	6	101	0	—
							0.7	52	4	115	6	117

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Twist Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
	2H. Fabrics of 2/1 twill weaves								
178	Cottonade or Hickory shirting (Fig. 2I)	cotton	0.6	W single, mock twist	25R	1	6,216	61.4	64.4
		cotton	0.6	F single	14R	29	5,527	31.2	35.6
179	Drill, middy, Duretta cloth, Jean, or Silesia (Fig. 2I)	cotton	0.9	W single	17R	4	17,353	99.0	65.5
		cotton	1.0	F single	23R	3	21,017	60.0	34.0
180	Drill, pocket (Fig. 2I)	cotton	0.9	W single	18R	11	11,222	77.0	64.4
		cotton	0.9	F single	14R	11	15,322	62.5	35.6
181	Emery cloth (Fig. 2I)	cotton	—	W single	—R	—	—	77.0	—
		cotton	—	F single	—R	—	—	66.0	—
182	Foulard (Fig. 2I)	silk	continuous	W single	3L	27	249,060	207.0	49.1
		silk	continuous	F single	0	—	140,700	106.0	53.3
183	Khaki (Fig. 2I)	cotton	0.9	W single	17R	5	20,622	105.0	60.3
		cotton	1.0	F single	15R	8	18,060	60.0	39.1
184	Denim, Dungaree, or Florentine (Fig. 2J)	cotton	0.9	W single	15R	7	5,858	67.0	77.6
		cotton	0.9	F single	10R	4	11,592	40.0	22.3
185	Kersey (Fig. 2J)	wool	0.9	W woolen	20R	6	5,905	48.0	46.1
		wool	0.8	F woolen	11L	7	5,813	48.0	53.4
186	Peau de soie (Fig. 2J)	silk	continuous	W single	14L	9	129,528	192.0	44.7
		silk	continuous	F single	0	—	35,490	64.0	55.3
	3H. Fabrics of 2/2 twill weave								
187	Grenfell cloth (Fig. 2K)	cotton	1.3	W 2-ply	15L, 10R	9, 11	33,432	96.0	67.8
		cotton	1.2	F 2-ply	15L, 10R	6, 2	34,801	100.0	32.1
188	Toweling (Fig. 2K)	linen	1.9	W single	6R	15	5,441	35.0	53.2
		linen	1.0	F single	5R	12	4,818	27.0	46.5
189	Blanket, wool (Fig. 2L)	wool	2.6	W woolen	4L	16	1,932	23.0	62.5
		wool	3.9	F woolen	4L	16	1,428	15.0	36.2
190	Eiderdown (Fig. 2L)	wool	3.1	W woolen	9R	8	5,068	33.0	—
		wool	1.9	F woolen	4R	12	4,609	34.0	—
191	Gabardine (Fig. 2L)	wool	3.1	W 2-ply worsted	17L, 11R	12, 5	14,372	114.0	66.9
		cotton	1.1	F 2-ply	20L, 12R	6, 7	12,768	58.0	33.1
192	Hair press cloth (Fig. 2L)	hair	15.0	W 3-ply woolen	3L, 1R	13, 40	193	26.0	73.7
		hair	13.4	F 6-ply woolen	1L, 1R	0, 20	84	6.0	26.7
193	Polo cloth (Fig. 2L)	camel's hair	3.0	W woolen	9L	5	3,878	30.0	36.9
		camel's hair	1.3	F woolen	9L	7	4,631	55.0	62.5
194	Serge, storm (Fig. 2L)	wool	3.3	W 2-ply worsted	10L, 6R	15, 2	9,080	54.0	64.5
		wool	5.1	F worsted	13R	7	16,338	37.0	35.3
195	Sheeting, twill (Fig. 2L)	cotton	0.9	W single	18R	9	16,800	77.0	51.0
		cotton	1.0	F single	15R	13	16,296	72.0	48.6
196	Shepherd check (Fig. 2L)	wool	2.1	W worsted	15R	6	24,091	32.0	25.5
		wool	3.8	W worsted	17R	12	26,611	32.0	24.7
		wool	3.5	F worsted	14R	11	23,402	32.0	28.0
		wool	2.1	F worsted	16R	10	24,352	32.0	25.5
197	Suède cloth (Fig. 2L)	wool	1.9	W woolen	11R	15	22,378	72.0	31.2
		wool	1.0	F woolen	—R	—	7,688	74.0	68.8

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation Dry pctg.	Elongation Wet pctg. of dry
178	9.86	0.0268	28.5	dyed, sized	6.4	0.2	8.8	141	5	121	17	106
							3.1	80	7	109	7	200
179	4.67	0.0081	36.8	bleached	0.0	0.1	3.5	95	2	119	8	213
							0.7	46	2	128	8	275
180	7.20	0.0197	30.8		4.5	1.1	3.8	117	5	113	22	200
							2.7	75	9	131	16	125
181	16.67	0.0223	9.0	coated	22.0	47.7	—	172	4	62	7	229
							—	114	4	46	17	94
182	0.96	0.0023	35.0	dyed, printed	8.3	0.7	—	17	9	112	0	—
							—	16	9	112	7	243
183	4.93	0.0116	35.7	dyed	5.2	0.8	1.6	79	3	124	7	314
							0.5	47	5	134	7	429
184	8.92	0.0241	29.0	dyed bleached	3.7	1.1	3.6	161	2	104	22	159
							0.7	53	5	142	11	155
185	10.66	0.0362	59.0	dyed, napped	0.4	0.9	—	33	5	94	17	300
							—	40	4	85	33	170
186	2.08	0.0060	35.5	weighted, dyed	6.3	6.8	—	42	4	88	22	150
							—	20	9	110	11	200
187	4.97	0.0105	—	mercerized, dyed	0.6	0.7	3.2	122	6	137	22	100
							+0.9	56	3	125	16	100
188	6.88	0.0111	19.8	bleached, calendered	2.4	0.6	—	67	14	127	0	—
							+0.5	36	19	92	5	200
189	12.47	0.0343	70.7	napped	2.9	1.0	—	67	3	101	25	68
							—	35	12	189	25	168
190	9.03	0.0344	36.3	napped	1.2	0.2	—	45	10	78	44	177
							—	22	12	77	60	130
191	8.15	0.0210	59.0	dyed	0.3	0.4	—	128	3	67	60	167
							—	55	4	133	11	145
192	127.33	0.2450	15.0		5.2	2.3	—	>300	—	—	—	—
							—	>300	—	—	—	—
193	11.57	0.0261	56.0	napped	1.5	0.2	—	41	7	129	17	488
							—	25	20	168	17	388
194	5.07	0.0150	56.0	bleached	1.4	0.7	—	56	5	77	17	32
							—	25	3	120	11	600
195	4.96	0.0125	81.0	bleached	0.7	0.0	5.5	69	4	100	8	125
							4.2	69	3	106	20	115
196	3.44	0.0100	39.0	dyed bleached	3.9	1.7	—	21	6	76	22	227
					dyed bleached			—	20	2	75	22	227
197	5.90	0.0179	53.0	dyed, napped	2.0	0.2	—	21	4	86	11	455
							—	12	17	117	17	294

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber		Yarn					
		Classification	Length	Construction	Twist		Count	No. per in. of fabric	Pctg. of fabric
						Deviation			
			inch		no. per in., direction	pctg.	yds. per lb.		
198	Zibeline (Fig. 2L)	wool	4.4	W 2-ply worsted	10L, 5R	9, 16	6,821	45.0	47.6
		wool	3.8	F woolen	12L	8	6,065	36.0	53.1
199	Surah (Fig. 2M)	silk	continuous	W single	13L	5	109,536	121.0	42.1
		regenerated cellulose	continuous	F multi-filament	3L	20	37,624	92.0	59.9
	4H. Fabrics of 1/3 twill weave								
200	Flannel, Canton (Fig. 2N)	cotton	0.9	W single	20R	7	23,024	92.0	44.7
		cotton	0.9	F single	11R	5	8,292	41.0	54.7
	5H. Fabrics of 3/1 twill weave (Fig. 2O)								
201	Leather cloth	cotton	0.9	W mock twist	20R	9	11,516	66.0	—
		cotton	1.0	F single	11R	7	8,030	38.0	—
202	Ticking	cotton	0.9	W single	13R	8	10,030	81.0	57.2
		cotton	0.9	F single	10R	9	11,340	70.0	42.8
	6H. Fabrics of 1/4 twill weave (Fig. 2 P)								
203	Broadcloth, wool, or Castor	wool	—	W woolen	13L	5	—	48	—
		wool	—	F woolen	14L	2	5,006	42.0	—
204	Filter cloth or Billiard cloth	wool	—	W woolen	—L	—	—	32.0	—
		wool	—	F woolen	—L	—	—	34.0	—
	7H. Fabrics of 4/1 twill weave (Fig. 2 Q)								
205	Galatea	cotton	1.0	W single	25R	3	21,588	120.0	60.5
		cotton	1.0	F single	21R	4	19,622	62.0	39.6
	8H. Fabrics of 3/3 twill weave (Fig. 2 R)								
206	Cheviot	wool	4.0	W 2-ply woolen	7L, 5R	13. 6	5,401	34.0	44.8
		wool	4.0	F 2-ply woolen	8L, 5R	14, 18	4,989	36.0	55.0
	I. Fabrics of steep twill weaves								
207	Merveilleux (Fig. 2S)	silk	continuous	W single	11L	5	141,120	398.0	56.9
		silk	continuous	F single	0	—	30,122	95.0	43.1
208	Poiret twill (Fig. 2T)	wool	3.4	W 2-ply worsted	15L, 2R	11, 15	20,143	117.0	64.4
		wool	3.5	F worsted	15R	5	27,997	88.0	35.2
	2I. Fabrics of combination twill weaves								
209	Tricotine (Fig. 2U)	cellulose acetate rayon	continuous	W multi-filament	5L	13	62,957	338.0	76.2
		spun silk	—	F single	36L	4	62,160	74.0	23.8
210	Whipcord (Fig. 3A)	wool	2.9	W 2-ply worsted	16L, 5R	9, 4	8,366	78.0	61.9
		wool	4.4	F worsted	14R	9	10,416	64.0	37.8
	J. Fabrics of skip twill weaves								
211	Skip twill (Fig. 3B)	wool	2.7	W 2-ply woolen	11L, 3R	13, 33	6,785	42.0	49.9
		wool	4.6	F 2-ply woolen	12L, 6R	8, 18	6,374	38.0	50.4
	2J. Fabrics of corkscrew twill weaves								
212	Velour (Fig. 3H)	wool	2.8	W woolen	16L	11	17,724	97.0	34.8
		wool	2.5	F woolen	12R	4	17,178	146.0	64.8
213	Charmeen (Fig. 3C)	wool	2.7	W worsted	19L	13	15,910	127.0	71.6
		wool	4.0	F worsted	15R	10	20,630	72.0	28.0

TABLE 1. (Continued) *Analysis of textiles*

								Breaking strength			Elongation at breaking load	
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Dry		Wet		
								Res.	Dev.	Res.	Dry	Wet
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
198	7.68	0.0243	—	dyed, napped	1.5	0.5	—	65	—	—	33	—
							—	39	—	—	11	—
199	2.46	0.0049	32.0	bleached, dyed, weighted	4.0	8.4	—	71	10	85	33	100
							—	45	3	57	17	129
200	5.18	0.0171	26.5	napped	0.5	0.1	4.0	60	12	123	8	212
							+0.5	26	5	127	16	138
201	31.30	0.0256	54.5	dyed, coated	1.5	35.5	—	98	3	104	0	—
							—	85	3	111	10	250
202	9.30	0.0220	32.0	dyed	3.3	0.7	4.6	118	6	115	22	182
							2.8	116	9	131	11	155
203	10.02	0.0089	52.5	dyed, napped	1.0	0.3	—	29	3	83	18	244
							—	29	4	76	40	188
204	33.02	0.1148	54.0	napped	1.7	0.6	—	131	1	88	50	166
							—	147	0	88	50	184
205	5.49	0.0124	28.5	dyed	4.4	1.9	2.8	66	16	141	12	142
							+0.5	43	12	144	15	167
206	8.37	0.0256	54.0	dyed, napped	1.9	0.2	—	49	5	88	22	250
							—	56	4	79	33	203
207	3.99	0.0083	30.3	dyed	4.3	2.2	—	164	9	99	22	227
							—	99	4	113	17	259
208	5.49	0.0156	51.0	bleached	2.5	6.1	—	82	2	61	33	308
							—	36	2	81	28	296
209	4.08	0.0108	39.1	dyed	0.7	0.3	—	66	5	70	21	157
							—	51	4	61	13	131
210	8.94	0.0227	59.0	dyed	0.9	0.7	—	120	1	67 ·	33	273
							—	74	3	77	22	255
211	7.18	0.0230	57.0	dyed	0.7	0.2	—	60	2	83	67	100
							—	49	7	71	67	100
212	9.41	0.0289	54.5	dyed, napped	1.4	0.4	—	74	2	66	44	152
							—	62	4	73	77	87
213	7.41	0.0185	55.5	bleached	1.5	0.1	—	132	3	53	55	167
							—	50	3	70	44	152

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Twist Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
214	Mackinaw or	wool	3.3	W woolen	8R	9	1,772	31.0	—
	Tartan (Fig. 3E)	wool	2.9	F woolen	6R	5	2,033	27.0	—
215	Shoe cloth	cotton	1.1	W 3-ply	13L, 13R	10, 7	17,321	114.0	52.3
	(Fig. 3G)	cotton	0.9	F single	16R	4	20,966	137.0	47.5
	K. Fabrics of simple satin weaves								
216	Sateen or Satine	cotton	1.2	W single	19R	6	39,522	94.0	39.0
	(Fig. 3J)	cotton	1.0	F single	17R	7	35,636	132.0	60.5
217	Hair cloth	cotton	1.0	W 2-ply	18L, 21R	10, 5	12,046	63.0	34.9
	upholstery	horse hair	continuous	F fiber	0	—	12,726	114.0	64.7
	(Fig. 3K)								
218	Brocade, corset	cotton	0.8	W 2-ply	24L, 18R	6, 8	23,310	161.0	60.8
	(Fig. 3L)	cotton	1.1	F 2-ply	18L, 14R	8, 9	15,389	69.0	37.6
219	Covert (Fig. 3L)	regenerated cellulose,	continuous,	W 2-ply union	15R, 13R, 3R	10, 5, 33	19,874	120.0	29.4
		wool	1.5						31.6
		wool	1.8	F 2-ply worsted	35L, 8R	14, 10	13,524	58.0	39.1
220	Crêpe meteor or Kitten's ear crêpe	silk	continuous	W single	0	—	70,560	345.0	44.6
	(Fig. 3L)	silk	continuous	F single	58, alternately 2L, 2R	6	29,014	77.5	55.1
221	Damask,	linen	1.2	W single	9R	10	17,136	77.0	54.2
	bleached linen	linen	1.2	F single	10R	22	17,388	66.0	45.9
	(Fig. 3L)								
222	Damask, mercerized cotton	cotton	0.9	W single	21R	20	14,868	61.2	54.8
	(Fig. 3L)	cotton	0.9	F single	23R	10	12,180	42.0	45.3
223	Damask, permanent-finished cotton (Fig. 3L)	cotton	1.0	W single	19R	22	18,900	79.7	45.0
		cotton	1.0	F single	15R	12	14,869	78.6	55.0
224	Damask, silver-bleached linen	linen	1.5	W single	18R	7	11,256	61.3	51.5
	(Fig. 3L)	linen	1.5	F single	13R	10	9,660	51.1	48.1
225	Doeskin (Fig. 3L)	wool	2.2	W 2-ply worsted	13L, 4R	6, 12	15,036	96.0	57.4
		wool	3.5	F worsted	11R	8	14,742	66.0	42.0
226	Lustrine or Sleeve lining (Fig. 3L)	cotton	1.0	W single	43R	4	23,940	138.0	63.2
		cotton	0.9	F single	17R	4	20,202	72.0	36.8
227	Satin Georgette	silk	continuous	W single	16R	3	147,000	232.0	54.1
	(Fig. 3L)	silk	continuous	F single	18, alternately 2L, 2R	8	103,236	127.0	45.9
228	Ticking, art, or Satin tick (Fig. 3L)	cotton	0.8	W single	19R	4	15,439	120.0	60.9
		cotton	0.8	F single	16R	4	12,768	60.0	38.6
229	Duvetyn (Fig. 3M)	cotton	1.1	W single	33R	2	41,496	130.0	42.5
		spun silk	—	F 2-ply	11L, 15R	8, 11	17,514	67.0	57.1
230.	Thibet (Fig. 3M)	cotton	1.0	W single	15R	8	10,164	39.0	10.3
		wool	1.4	F woolen	8R	12	12,751	28.0	89.6
231	Satin, ciré	silk	continuous	W single	0	—	126,000	476.0	60.3
	(Fig. 3N)	silk	continuous	F single	76, alternately 2L, 2R	1	45,452	103.0	39.7
232	Charmeuse	silk	continuous	W single	13L	13 ·	191,772	272.0	41.8
	(Fig. 3O)	spun silk	—	F single	5R	28	47,569	100.0	57.6
233	Crêpe satin	silk	continuous	W single	0	—	103,320	456.0	54.1
	(Fig. 3O)	silk	continuous	F single	78, alternately 2L, 2R	5	43,546	118.0	46.2

TABLE 1. (Continued) *Analysis of textiles*

				Fabric								
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet		
								Res.	Dev.	Res.	Dry	Wet
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
214	23.27	0.0730	58.0	dyed, napped	2.4	1.9	—	92	3	85	67	100
							—	62	3	87	67	84
215	7.94	0.0153	35.5	bleached	0.6	0.2	2.3	124	2	102	8	213
							0.3	92	8	102	8	100
216	3.35	0.0058	35.8	bleached, mercerized, Schreinerized	1.7	0.1	1.3	22	3	186	0	—
							0.6	44	8	159	12	183
217	8.46	0.0201	22.0	dyed	1.4	0.7	—	83	3	122	10	330
							—	195	1	83	33	203
218	7.12	0.0127	40.5	bleached dyed, mercerized	6.8	0.3	6.1	118	3	103	5	440
							1.0	83	4	105	5	220
219	6.48	0.0167	52.5	bleached, dyed	1.5	0.1	—	72	0	40	40	180
							—	45	4	56	33	248
220	3.46	0.0097	40.0	dyed	2.0	0.4	—	89	4	92	17	206
							—	70	5	86	50	156
221	5.06	0.0063	71.5	bleached, calendered	2.2	0.1	2.2	94	13	110	0	—
							+0.5	78	8	94	0	—
222	4.46	0.0074	57.7	bleached, Schreinerized	0.5	0.1	7.2	62	12	108	0	—
							+0.2	47	12	94	11	155
223	5.60	0.0079	74.8	bleached, permanent-finished, Schreinerized	0.9	0.4	2.7	54	10	120	0	—
							0.9	67	9	116	11	155
224	6.03	0.0101	75.9	bleached, calendered	2.1	0.3	5.4	81	5	131	0	—
							+4.2	58	8	140	0	—
225	6.32	0.0160	55.0	dyed	1.0	0.1	—	68	1	79	33	203
							—	37	8	100	33	203
226	5.25	0.0072	42.5	dyed, water-resistant	3.3	0.9	2.1	100	3	108	25	83
							1.3	44	2	111	25	114
227	1.66	0.0063	40.0	dyed	2.9	0.4	—	54	9	80	33	100
							—	35	5	97	40	125
228	7.38	0.0125	32.3	bleached, printed	2.9	0.4	3.5	140	4	103	5	340
							0.0	70	3	123	17	100
229	4.10	0.0163	35.3	dyed, napped	2.3	0.2	—	52	2	139	11	109
							—	56	5	57	33	55
230	20.04	0.0520	31.0	dyed, napped	2.5	2.4	—	45	4	102	11	100
							—	71	4	97	50	100
231	3.83	0.0058	39.0	weighted, dyed, ciré	8.3	42.4	—	88	3	82	16	213
							—	34	7	129	16	294
232	2.09	0.0056	39.0	dyed	4.8	0.3	—	58	3	109	12	208
							—	57	3	84	10	160
233	3.54	0.0068	39.0	weighted, dyed	7.0	37.6	—	89	5	88	20	200
							—	43	5	109	22	255

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
234	Damask, double	linen	1.5	W single	11R	14	15,035	76.0	53.5
	(Fig. 3O)	linen	1.0	F single	15R	11	21,600	75.0	46.5
235	Satin, Baronette	regenerated cellulose	continuous	W multi-filament	0	—	30,702	128.0	68.7
	(Fig. 3O)	cotton	1.3	F 2-ply	16L, 18R	7, 9	25,830	50.0	29.3
236	Satin, Duchesse	silk	continuous	W single	14L	9	133,812	289.0	54.9
	(Fig. 3O)	silk	continuous	F single	0	—	70,308	124.0	45.1
237	Venetian, Farmer's	cotton	1.1	W 2-ply	15L, 15R	9, 5	36,053	179.0	60.0
	satin, or Warp sateen (Fig. 3O)	cotton	1.1	F single	21L	5	21,848	72.0	39.8
238	Ribbon (Fig. 3P)	wool	3.7	W 2-ply worsted	11L	13	10,710	95.0	55.6
		regenerated cellulose	continuous	W multi-filament	0	—	29,753	95.0	21.5
		wool	4.4	F 2-ply worsted	11L	5	11,701	40.0	22.4

L. Fabrics of double satin weaves

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
239	Imperial sateen	cotton	0.9	W 2-ply	14L, 12R	13, 10	9,122	72.0	26.6
	(Fig. 4A)	cotton	1.0	F single	14R	17	16,246	201.0	73.2

2L. Fabrics of granite weaves

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
240	Chain filter cloth	cotton	0.9	W 2-ply	11L, 8R	9, 11	3,693	38.0	63.6
	(Fig. 4B)	cotton	1.0	F 4-ply	4L, 17R	10, 9	3,266	66.0	36.4
241	Pebble cloth	wool	2.6	W 2-ply woolen	8L, 2R	16, 30	5,549	37.0	53.6
	(Fig. 4C)	wool	2.7	F woolen	5R	12	5,328	33.0	45.9

J. Fabrics of simple pointed twill weaves

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
242	Coutil (Fig. 4D)	cotton	1.0	W single	29R	8	25,402	147.0	59.4
		cotton	1.1	F single	20R	7	20,681	83.0	40.9
243	Tweed (Fig. 4E)	wool	4.3	W woolen	6L	8	2,540	22.1	54.9
		wool	4.3	W 2-ply grandrelle	6R, 4L	8, 30	1,699	0.9	
		wool	2.6	F woolen	7L	15	2,338	19.2	44.8
		wool	2.6	F 2-ply grandrelle	6R, 6L	8, 23	1,816	0.8	

2J. Fabrics of fancy pointed twill weaves

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
244	Birdseye or	cotton	1.1	W single	19R	10	19,706	65.5	42.1
	Diaper cloth (Fig. 4F)	cotton	0.9	F single	13R	7	10,072	45.0	57.8
245	Brighton cloth	cotton	1.0	W 3-ply	10L, 12R	5, 9	3,847	33.0	50.8
	(Fig. 4H)	cotton	0.9	F 3-ply	4L, 14R	0, 11	3,757	27.0	49.3
246	Figured twill or	regenerated cellulose (76.7%),	13.8	W combination	9L	9	7,913	44.0	48.7
	Ornamental twill (Fig. 4I)	wool	2.9						
		regenerated cellulose (76.7%),	3.9	F combination	10L	13	7,476	43.0	51.0
		wool	2.3						
247	Honeycomb or	cotton	1.0	W 2-ply cordonnet	8L, 9R	10, 10	4,137	36.0	54.1
	Waffle cloth (Fig. 4G)	cotton	1.0	F 2-ply cordonnet	5L, 10R	8, 5	3,933	27.0	46.0

TABLE 1. (Continued) *Analysis of textiles*

				Fabric							
	Weight	Thick-ness	Width	Finish	Water extract	Ash	Shrink-age	Breaking strength			Elongation at breaking load	
								Dry		Wet		
								Res.	Dev.	Res.	Dry	Wet
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
234	5.17	0.0066	71.0	bleached, calendered	1.2	0.1	0.0	91	9	87	2	200
							1.0	79	14	86	2	150
235	3.54	0.0090	39.0	bleached	1.0	0.2	3.9	67	6	52	17	194
							0.6	24	5	154	12	142
236	2.55	0.0044	36.0	weighted, dyed	5.4	14.0	—	60	2	90	16	206
							—	46	7	107	16	206
237	- 4.95	0.0080	54.0	mercerized, dyed	0.7	0.2	1.4	84	9	118	5	220
							1.4	35	8	149	11	155
238	9.13	0.0206	4.2	dyed	1.3	0.2	—	142	1	91	33	203
				bleached dyed			—	27	18	115	5	1200
239	11.84	0.0343	31.0	dyed, napped	4.1	0.4	2.0	93	2	114	5	220
							2.0	232	3	112	22	227
240	19.42	0.0412	32.5		1.8	0.8	4.3	>300	—	—	—	—
							1.7	221	5	121	11	100
241	7.69	0.0232	56.0	dyed	1.0	0.2	—	65	2	82	50	134
							—	50	2	78	50	134
242	6.17	0.0117	36.0	dyed	0.6	0.2	2.5	114	5	111	22	150
							1.9	95	7	128	11	200
243	11.52	0.0137	55.8	dyed	4.8	2.5	—	52	4	92	11	236
							—	20	3	100	6	250
244	4.59	0.0134	26.5	bleached	0.7	0.4	3.9	47	4	115	8	200
							+2.2	52	7	121	22	150
245	10.26	0.0308	—	bleached	0.7	0.2	5.3	95	11	131	17	41
							+3.4	84	4	130	33	85
246	6.61	0.0183	56.0	bleached	0.9	0.4	—	43	4	37	17	94
							—	41	3	34	22	150
247	9.19	0.0345	80.0	bleached	0.5	0.2	1.6	121	2	97	17	100
							+5.6	90	3	106	35	97

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Twist Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
	2I. Fabrics of broken twill weaves								
248	Entwining twill	wool	2.0	W woolen	17L	8	5,174	45.0	52.4
	(Fig. 4J)	wool	2.0	F woolen	14L	5	5,653	40.0	47.5
249	Tape (Fig. 4K)	cotton	1.1	W 2-ply	28L, 5R	7, 12	26,998	92.0	55.2
		regenerated cellulose	continuous	F multi-filament	0	—	21,596	92.0	43.5
	3I. Fabrics of curved twill weaves								
250	Curved twill	cotton	1.0	W 4-ply	9L, 13R	5, 4	4,978	37.0	60.3
	(Pl. IF)	linen	6.5	F single	6R	5	6,740	32.0	39.2
	G. Warp-backed fabrics								
251	Alhambra (Pl. IG)	cotton	1.1	W single	18R	12	20,446	28.0	10.4
		cotton	1.1	W single	17R	15	12,130	55.0	33.2
		cotton	1.0	F single	7R	13	3,143	22.9	56.6
252	Beaver cloth	wool	0.8	W woolen	13L	5	5,712	80.0	—
	(Fig. 5A)	wool	0.9	F woolen	11R	4	5,796	80.0	—
253	Frieze (Fig. 5B)	wool	1.7	W woolen	5L	16	1,697	26.0	47.5
		wool	3.1	F woolen	6L	12	1,831	26.0	48.7
254	Madras shirting	cotton	1.2	Wg single	23R	5	35,389	78.0	62.4
	(Pl. II I)	cotton	1.1	Wf 2-ply	13L, 11R	6, 18	9,635	8.0	9.7
		cotton	1.1	F single	13R	8	25,897	72.0	44.9
255	Satin gros grain	silk	continuous	W single	0	—	76,608	576.0	81.9
	(Fig. 5C)	silk	continuous	F single	56L	3	46,603	92.0	18.8
256	Satin royal or	silk	continuous	W single	0	—	212,016	463.0	59.1
	Double face satin (Fig. V D)	silk	continuous	F single	73L	9	90,720	130.0	38.5
257	Swiss, lappet dot	cotton	1.0	Wg single	21R	.8	55,398	75.0	48.4
	(Pl. III A)	cotton	1.0	Wf 2-ply	—L, —R	—	6,300	—	16.0
		cotton	0.9	F single	20R	6	71,476	72.0	35.6
258	Tuck or Pleat	cotton	1.3	Wg 2-ply	33L, 5R	2, 18	34,965	90.0	7.3
	cloth (Fig. V I)	cotton	1.3	Wt 2-ply	33L, 5R	2, 18	34,965	60.0	42.6
		cotton	1.1	F single	23R	13	42,252	84.0	50.1
	2G. Filling-backed fabrics								
259	Blanket, Jac-	cotton	0.9	W single	16R	12	12,499	43.0	24.1
	quard, Bathrobe blanket, or Re- versible filling (Fig. 5E)	cotton	0.9	F single	6R	11	4,224	38.0	75.6
260	Brocatelle	cotton	1.3	W 2-ply	21L, 1R	16, 40	25,578	90.4	24.6
	(Pl. I H)	cotton	1.3	W 2-ply	21L, 1R	16, 40	35,860	22.6	4.4
		linen	2.7	F single	8R	14	5,200	44.0	61.2
		regenerated cellulose	continuous	F multi filament	4L	18	27,502	44.0	10.1
261	Damask, com-	cotton, copper-silver (72%)	1.3, continuous	W 3-ply lamé	48R, 12L, 11R	3, 8, 9	12,298	175.0	60.3
	pound (Pl. I I)	cotton, copper-silver (69%)	1.3, continuous	F 5-ply lamé	33R, 25L, 4R	5, 4, 12	5,003	38.0	32.6
		cotton	1.0	F 2-ply	16L, 13R	7, 6	23,285	38.0	6.6
262	Fiber fabric	paper	continuous	W 1¼-inch strip	2L	0	361	6.0	18.3
	(Fig. 5G)	cotton	1.0	F 2-ply	12L, 9R	8, 7	5,956	10.0	6.8
		paper	continuous	F ¾-inch strip	2L	15	496	13.0	36.9
		cotton (34%), wool	0.8, 4.0	F 3-ply covered	3L, 13R	20, 5	512	13.0	37.8

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation Dry pctg.	Wet pctg. of dry
248	8.71	0.0243	56.0	dyed, napped	1.3	0.9	—	47	3	92	22	227
							—	40	3	88	33	170
249	4.14	0.0100	0.8	dyed	0.6	0.4	2.4	44	2	116	11	145
							1.3	—	—	—	—	—
250	7.19	0.0215	50.5		1.2	0.6	3.7	99	3	135	50	44
							1.9	54	6	96	33	30
251	8.06	0.0280	—	bleached dyed	0.9	0.1	5.6	68	6	106	3	367
				bleached			+1.6	77	4	113	11	100
252	19.51	0.0540	57.0	dyed, napped	1.3	1.2	—	82	3	75	33	182
							—	94	2	69	67	100
253	20.35	0.0640	60.0	dyed, napped	2.1	4.1	—	46	2	89	22	200
							—	40	3	83	33	133
254	3.85	0.0095	32.5	bleached, dyed	3.8	0.5	2.6	48	5	119	11	200
							2.5	43	2	142	15	200
255	5.34	0.0108	40.0	weighted, dyed	3.4	24.9	—	157	3	92	33	133
							—	38	3	92	33	167
256	2.13	0.0050	37.5	dyed	4.2	23.6	—	58	3	79	17	165
							—	28	4	82	17	259
257	1.61	0.0053	—	bleached	3.2	0.1	1.6	19	8	84	0	—
							2.0	3	53	100	0	—
258	6.16	—	42.0	.	2.5	1.4	0.6	—	—	—	—	—
							3.5	81	2	113	11	200
259	8.00	0.0260	36.5	dyed, napped	2.0	0.8	6.2	44	6	118	11	155
							+1.2	27	9	226	50	100
260	9.52	0.0217	50.0	mercerized, dyed	1.4	0.8	1.8	85	4	108	10	220
				mercerized, dyed dyed, embossed			2.7	140	7	147	0	—
261	14.44	0.0183	24.0		1.2	32.7	—	97	10	96	8	·100
							—	85	3	95	8	138
262	40.88	0.1690	—	dyed	2.4	1.5	—	95	· 9	65	8	338
							—	168	4	74	11	145

RACHEL EDGAR

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length (inch)	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
263	Moleskin or	cotton	1.0	W 3-ply	13L, 15R	8, 5	9,509	50.0	25.9
	Beaverteen (Fig. 5H)	cotton	0.8	F single	13L	4	19,085	226.0	73.8
264	Molleton (Fig. 5J)	cotton	1.1	W single	13R	5	12,600	45.0	12.0
		cotton	0.9	F single	3R	10	2,160	60.0	88.1
265	Silence cloth or	cotton	1.0	W single	13R	12	8,610	71.0	37.2
	Table felt (Fig. 5F)	cotton	1.0	F single	4R	18	3,095	44.0	62.8
266	Swiss, swivel dot	cotton	0.7	W single	17R	5	62,664	68.0	48.2
	Pl. III B)	cotton	0.7	Ff 3-ply	—L, —R	—	6,300	—	16.2
		cotton	0.9	Fg single	25R	16	53,634	43.0	35.6
267	Swiss, tissue dot	cotton	1.1	W single	27R	3	52,450	75.0	57.3
	(Pl. III C)	cotton	0.8	F single	24R	3	68,242	52.0	10.7
		cotton	—	Ff single	—	—	—	—	10.7
	G. Warp pile fabrics								
268	Frisé (Fig. 6A)	cotton	0.8	Wg 3-ply	15L, 19R	11, 14	6,392	34.0	17.9
		linen	4.7	Wp 3-ply	6L, 10R	17, 15	5,775	32.0	66.7
		cotton	0.8	F 2-ply	24L, 9R	10, 10	13,314	63.0	15.4
269	Moquette	cotton	1.1	Wg 2-ply	17L, 6R	5, 3	8,040	17.0	8.4
	(Fig. 6B)	worsted	6.6	Wp 2-ply worsted	7L, 5R	11, 8	7,080	34.0	40.4
		cotton	1.1	Ww 3-ply	17L, 5R	9, 10	7,830	34.0	17.1
		cotton	1.1	Ww 3-ply	9L, 5R	6, 6	4,076	17.0	16.1
		cotton	0.9	F 2-ply	13L, 9R	7, 8	11,130	35.0	15.0
270	Plush, upholstery	cotton	0.9	W 3-ply	16L, 16R	9, 9	8,236	31.0	18.7
	(Fig. 6C)	mohair	—	Wp single	—	—	—	—	56.5
		cotton	1.1	Fg single	10R	5	5,969	54.0	29.8
271	Terry cloth or	cotton	0.9	W single	13R	10	14,146	73.0	77.8
	Turkish toweling (Fig. 6D)	cotton	1.0	F single	13R	12	12,264	31.0	17.6
272	Velours	cotton	1.0	Wg 2-ply	21L, 17R	17, 8	13,633	43.0	17.2
	(Fig. 6E)	cotton	—	Wp single	—	—	—	—	57.5
		cotton	1.1	F 2-ply	9L, 10R	9, 9	8,484	44.0	25.3
273	Velvet, chiffon, or	silk	continuous	Wg single	17L	5	98,448	86.0	10.9
	Transparent valvet	silk	—	Wp single	—	—	—	—	67.5
	(Fig. 6F)	silk	continuous	F single	18R	3	73,912	110.0	21.6
274	Velvet, cut	silk	continuous	Wg single	38L	2	117,012	96.0	17.9
	(Fig. 6G)	regenerated cellulose	—	Wp multi-filament	—	—	—	—	64.6
		silk	continuous	F single	39R	3	148,428	89.0	17.5
275	Whitney	wool	0.9	W woolen	10R	11	3,671	56.0	54.1
	(Fig. 6H)	wool	1.7	F woolen	10L	8	3,881	48.0	44.0
	2G. Filling pile fabrics								
276.	Bolivia	wool	2.6	W 2-ply woolen	13L, 7R	11, 7	9,929	46.0	29.5
	(Fig. 7A)	wool	1.1	Fg woolen	11L	5	3,105	28.0	30.0
		wool	—	Fp woolen	—	—	—	28.0	40.5
277	Chinchilla	wool	3.1	W woolen	9L	12	3,570	28.0	42.2
	(Fig. 7B)	wool	3.1	F woolen	11L	7	1,248	24.0	57.2
278	Corduroy, Boy-duroy, Cotton, Genoa, or Velvet cords, or Hollow cut (Fig. 7E)	cotton	0.9	W single	22R	5	14,683	48.0	23.4
		cotton	1.0	Fg single	17R	6	12,172	27.0	16.0
		cotton	—	Fp single	—	—	—	—	60.6

TABLE 1. (Continued) *Analysis of textiles*

				Fabric								
	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet	Dry	Wet
								Res.	Dev.	Res.		
No.	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
263	12.17	0.0350	28.4	bleached	0.3	0.1	1.1	91	4	96	8	213
							0.8	193	15	112	12	50
264	27.42	0.1000	39.5	bleached, napped	0.3	0.1	0.0	70	4	121	33	100
							+1.4	81	5	158	33	152
265	29.70	0.0489	26.0	napped	2.4	0.8	2.4	128	5	125	30	183
							0.0	50	9	226	22	250
266	1.23	0.0064	29.5	bleached	2.2	0.1	0.5	16	10	88	5	—
							0.8	7	14	100	5	220
267	1.48	0.0053	34.8	bleached	1.4	0.2	0.7	18	10	111	0	—
							2.6	8	11	100	11	—
268	16.29	—	52.0	dyed mercerized, dyed lashed cut and loop pile, dyed	1.0	0.4	2.7	87	7	160	33	152
							1.9	78	4	128	17	129
269	14.14	—	52.0	dyed loop pile	2.0	0.7	—	88	4	125	5	220
							—	49	7	118	11	200
270	16.98	—	52.2	dyed lashed cut pile	0.8	0.1	—	58	9	122	11	200
							—	108	5	115	17	147
271	9.03	—	17.5	bleached, loop pile	0.0	0.0	0.3	23	10	100	12	142
							+3.0	30	6	97	22	136
272	11.91	—	52.0	dyed cut pile-up	0.3	0.2	0.0	52	5	117	5	440
							2.1	76	5	141	5	440
273	4.16	—	39.0	bleached cut pile-up	1.8	0.6	—	34	2	59	5	220
							—	54	6	69	5	340
274	2.16	—	38.0	dyed lashed cut pile	1.4	0.4	—	24	9	79	22	200
							—	19	2	100	22	200
275	18.52	0.0071	60.0	dyed, napped	0.3	1.4	—	52	6	94	33	133
							—	35	3	103	40	125
276	10.55	—	54.0	dyed	0.9	0.2	—	55	3	73	33	227
				lashed cut pile			—	23	6	96	17	294
277	11.49	0.0150	57.5	dyed, napped	0.9	0.1	—	53	4	79	33	233
							—	16	6	88	33	233
278	7.97	—	36.0	bleached	0.8	0.1	1.2	39	4	90	8	213
							+0.1	17	4	135	11	155
				cut, lashed and pile up								

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber		Construc-tion	Yarn				
		Classifica-tion	Length		Twist		Count	No. per in. of fabric	Pctg. of fabric
					no. per in., direction	Devia-tion pctg.	yds. per lb.		
			inch						
279	Montagnac or	wool	1.3	W woolen	11L	12	5,154	55.0	—
	Astrakhan (Fig. 7D)	wool	0.9	F woolen	8L	23	4,095	110.0	—
280	Velveteen or Wal-	cotton	1.2	W single	15L	6	31,214	81.0	25.3
	demar (Fig. 7E)	cotton	1.0	Fg single	12L	3	33,726	56.0	16.7
		cotton	—	Fp single	—	—	—	—	58.0
	F. Ply fabrics								
281	Buckram	cotton	—	Wo single	—R	—	—	16.0	—
	(Pl. IV A)	cotton	—	Wr single	—R	—	—	40.5	—
		cotton	—	Fo single	—R	—	—	12.0	—
		cotton	—	Fr single	—R	—	—	32.5	—
282	Willow	willow	continuous	Wo strip	0	—	6,728	15.0	37.2
	(Pl. III D)	cotton	0.7	Wr single	21R	5	19,085	16.0	10.5
		willow	continuous	Fo strip	0	—	3,757	9.5	35.5
		cotton	0.6	Fr single	21R	2	22,764	24.0	15.2
	H. Fabrics of a reverse surface of floating yarns								
283	Piqué, fleece-back	cotton	0.8	Wo single	16R	6	26,855	56.0	20.1
	(Pl. III E)	cotton	1.1	Wr single	17R	6	124,488	30.0	10.3
		cotton	1.0	Fo single	19R	4	35,338	71.0	20.0
		cotton	0.9	Fr single	8L	3	7,358	36.0	48.9
	2H. Doubly transposed fabrics								
284	Kidderminister	cotton	1.2	Wo single	24R	3	33,852	47.0	23.0
	cloth or Ingrain	cotton	1.2	Wr single	24R	3	33,852	47.0	24.1
	(Pl. III F)	cotton	1.1	Fo 2-ply	16R, 15L	9, 9	24,520	41.0	26.4
		regenerated cellulose	continuous	Fr multi-filament	0	—	28,585	41.0	24.5
	2G. Fast-back fabrics								
285	Mitcheline or	cotton	1.0	W single	80R	4	19,253	53.6	23.2
	Patent satin	cotton	1.0	Fo single	70R	3	22,394	26.4	13.2
	(Fig. 7F)	cotton	1.0	Fr single	17R	9	2,570	26.4	64.1
286	Piqué, Toilet	cotton	1.3	W single	22R	9	56,246	175.0	40.5
	cloth, or Welt	cotton	1.3	Ww 2-ply	20L, 7R	9	27,838	51.0	17.9
	(Fig. 7G)	cotton	1.3	Fo single	25R	10, 7	92,064	148.0	18.9
		cotton	1.3	Fr single	15R	9	36,834	74.0	22.6
287	Tapestry, up-	cotton	0.6	W 2-ply	12L, 15R	13, 5	29,500	39.0	9.2
	holstery (Pl. IV B)	cotton	0.8	W 2-ply	21L, 8R	7, 6	12,348	39.0	19.3
		cotton	0.6	W 2-ply	21L, 8R	7, 6	15,187	39.0	16.9
		cotton	1.0	F single	24R	4	85,522	32.0	5.1
		cotton	1.0	F single	14R	16	8,058	64.0	48.8
	F. Half-fast-back fabrics								
288	Marseilles	cotton	0.9	Wo single	16R	6	22,823	60.0	12.6
	(Pl. III G)	cotton	0.9	Wr single	26R	4	12,835	30.0	10.6
		cotton	1.0	Fo single	29R	5	23,461	55.0	9.6
		cotton	0.6	Fr single	28R	2	22,848	27.5	4.9
		cotton	0.9	Fw single	6R	7	2,397	27.5	61.4
	2F. Wadded blister fabrics								
289	Matelassé	regenerated cellulose	continuous	Wo multi-filament	6L	13	41,731	129.0	38.6
	(Pl. IV C)	spun silk	—	Wr 2-ply	15L, 15R	5, 19	38,396	42.0	13.1
		spun silk	—	Fo single	8R	9	48,644	41.0	10.1
		spun silk	—	Fr single	6R	10	51,887	21.0	5.3
		spun silk	—	Fw 2-ply	4L, 10R	15, 11	7,983	18.0	31.9

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight	Thickness	Width	Finish	Water extract	Ash	Shrinkage	Breaking strength			Elongation at breaking load	
								Dry		Wet	Dry	Wet
								Res.	Dev.	Res.		
	oz. per sq. yd.	in.	in.		pctg.	pctg.	pctg.	lb.	pctg.	pctg. of dry	pctg.	pctg. of dry
279	26.03	0.0885	60.0	dyed, napped	2.3	2.7	—	52	3	121	17	294
							—	67	6	73	33	76
280	6.13	—	35.0	dyed	1.5	0.9	1.6	40	6	118	11	100
							+1.0	15	0	147	17	129
281	5.48	0.0317	24.0	cut pile up dyed, sized	24.5	0.7	—	61	11	75	0	—
							—	56	11	41	0	—
282	4.05	0.0300	24.0	sized	15.5	0.5	—	45	13	53	0	—
							—	40	21	85	0	—
283	6.51	0.0220	27.5	bleached, napped	1.2	0.4	1.0	35	4	106	7	157
							0.0	52	10	106	20	81
284	3.34	0.0119	34.5	bleached, dyed	0.7	0.3	1.2	44	3	105	8	138
							0.8	32	6	78	22	50
285	9.00	0.0322	86.6	bleached	2.0	0.0	0.0	52	2	96	8	200
							3.0	135	8	112	12	117
286	5.04	0.0130	37.0	bleached	0.2	0.1	1.5	80	2	101	0	—
							2.5	79	2	95	8	135
287	9.90	0.0302	50.0	dyed	0.9	0.9	4.1	93	3	129	25	176
							3.4	116	5	123	11	200
288	13.35	0.0448	—	bleached	0.7	0.1	4.5	66	9	95	17	65
							1.1	166	3	101	22	22
289	4.80	0.0167	39.0	dyed	2.1	1.3	—	68	6	56	11	100
							—	51	4	71	17	100

TABLE 1. *Analysis of textiles*

No.	Name of fabric	Fiber Classification	Length inch	Construction	Twist no. per in., direction	Deviation pctg.	Count yds. per lb.	No. per in. of fabric	Pctg. of fabric
	5E. Double fabrics								
290	Albert cloth	wool	1.7	Wo woolen	14L	5	4,172	34.0	21.2
	(Pl. IV D)	wool	3.3	Wr woolen	8L	3	3,251	21.0	27.1
	(Fig. 2, J & L)	cotton, regenerated cellulose	0.9, continuous	Wb combination	11L	10	9,929	6.0	3.3
		cotton	0.9	Wb 2-ply	18L, 16R	8, 4	6,213	6.0	2.0
		wool	1.7	Fo woolen	14L	5	7,162	27.0	22.0
		wool	1.3	F woolen	11L	3	3,284	18.0	23.5
	E. Simple gauze fabrics								
291	Bagging, gauze	cotton	0.8	W 8-ply	3L, 7R	10, 11	731	8.0	54.8
	(Pl. III H)	cotton	0.9	F 10-ply	3L, 7R	0, 19	605	5.0	45.2
292	Marquisette	cotton	1.1	W single	22R	7	40,958	68.0	62.4
		cotton	1.1	F single	20R	5	34,902	34.0	36.5
293	Mosquito bar	cotton	1.1	W single	26R	4	22,549	20.0	68.1
		cotton	0.9	F single	14R	11	19,463	10.0	31.9
294	Screen cloth	cotton	0.7	W single	20R	4	10,030	28.0	35.0
		cotton	0.7	F 2-ply	14L, 14R	9, 7	6,278	14.0	65.0
295	Tire breaker fabric or Inserts	cotton	1.0	W 12-ply hawser	6L, 5R, 18R	2, 14, 19	1,015	14.0	53.5
		cotton	1.1	F 24-ply hawser	5L, 4R, 18R	2, 12, 2	592	8.0	46.4
	2E. Fancy gauze fabrics								
296	Bolting cloth	silk in the gum	continuous	W single	11L	19	202,500	237.0	—
	(Pl. III I)	silk in the gum	continuous	F single	12L	10	152,656	148.0	—
297	Lace cloth or Cellular cloth	cotton	0.9	W single	29R	3	45,914	66.0	51.9
	(Pl. IV F)	cotton	1.0	F single	30R	4	41,731	56.0	47.4
298	Madras gauze	cotton	1.5	W twist on twist	23R, 28R	19, 4	37,993	56.0	40.4
	(Pl. IV G)	cotton	1.5	Fg twist on twist	27R, 31R	5, 2	40,345	32.0	25.3
		cotton	1.2	Ff single	11R	11	11,021	32.0	33.9
299	Ondulé, warp	cotton	1.4	W single	27R	5	38,102	68.0	44.3
	(Pl. IV E)	cotton	1.4	F single	27R	5	40,891	57.0	55.7
300	Russian-Cord shirting	cotton	1.3	Wg single	31R	4	36,532	84.0	34.1
	(Pl. IV H)	cotton	1.1	Ww 2-ply	21L, 6R	8, 7	17,900	12.0	11.8
		cotton	1.4	Wwh 2-ply	42L, 6R	6, 7	48,997	8.0	19.4
		cotton	1.3	F single	19R	8	38,464	88.0	34.7

TABLE 1. (Continued) *Analysis of textiles*

No.	Weight oz. per sq. yd.	Thickness in.	Width in.	Finish	Water extract pctg.	Ash pctg.	Shrinkage pctg.	Breaking strength Dry Res. lb.	Dry Dev. pctg.	Wet Res. pctg. of dry	Elongation at breaking load Dry pctg.	Wet pctg. of dry
290	15.58	0.0565	54.5	dyed, napped	1.7	2.2	—	61	4	90	16	275
							—	40	3	90	33	182
291	11.00	0.0290	23.0		1.6	0.7	11.0	89	6	132	25	112
							10.0	80	5	138	17	147
292	1.51	0.0068	48.0	bleached	0.1	0.1	1.9	20	2	105	0	—
							0.2	11	7	100	0	—
293	0.82	0.0103	58.5	sized	15.3	0.5	4.8	13	2	92	0	—
							1.5	2	25	190	0	—
294	3.80	0.0153	35.9	bleached, sized	50.3	0.2	—	26	2	50	0	—
							—	28	4	68	0	—
295	15.82	0.0560	—		1.9	0.7	—	191	4	—	60	—
							—	213	2	—	22	—
296	1.35	0.0036	40.0		3.5	0.9	—	37	3	105	17	259
							—	37	5	108	17	259
297	1.59	0.0052	34.5	dyed	0.6	0.4	6.6	18	2	158	0	—
							1.4	12	1	144	5	160
298	2.01	0.0107	38.0	bleached dyed bleached	0.9	0.5	6.5	26	7	119	16	206
							18.7	13	12	115	16	419
299	2.00	0.0068	35.5	dyed	0.9	0.3	2.5	18	1	167	9	122
							12.5	12	4	108	28	178
300	3.25	0.0092	32.0	bleached, dyed bleached mercerized, dyed bleached, dyed	0.5	0.1	1.0	41	5	117	11	145
							0.7	35	5	106	8	200

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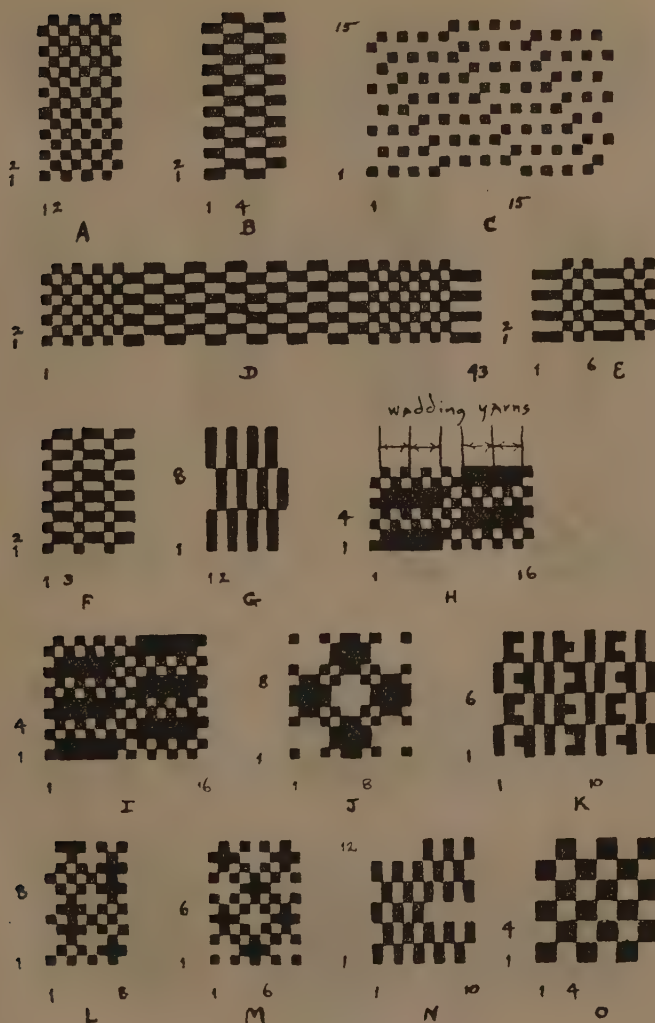
Fig. 1.

A. Plain weave*
B. Simple warp rib weave
C. Agaric
D. Crêpe seersucker
E. Dimity, striped

F. Gros de Londres
G. Webbing, elastic
H. Bedford cord, cotton
I. Bedford cord, wool
J. Canvas, Java

K. Faille
L. Linear zigzag
M. Parachute cloth
N. Toweling, huckaback
O. Simple basket weave

* Black squares represent warp yarns and white squares filling yarns.

Fig. 2.

A.	Barathea, silk	
B.	Barathea, wool	
C.	Dimity, barred	
D.	Oxford cloth	
E.	Oblique rib weave	
F.	1/2 Left twill weave	
G.	1/2 Right twill weave	
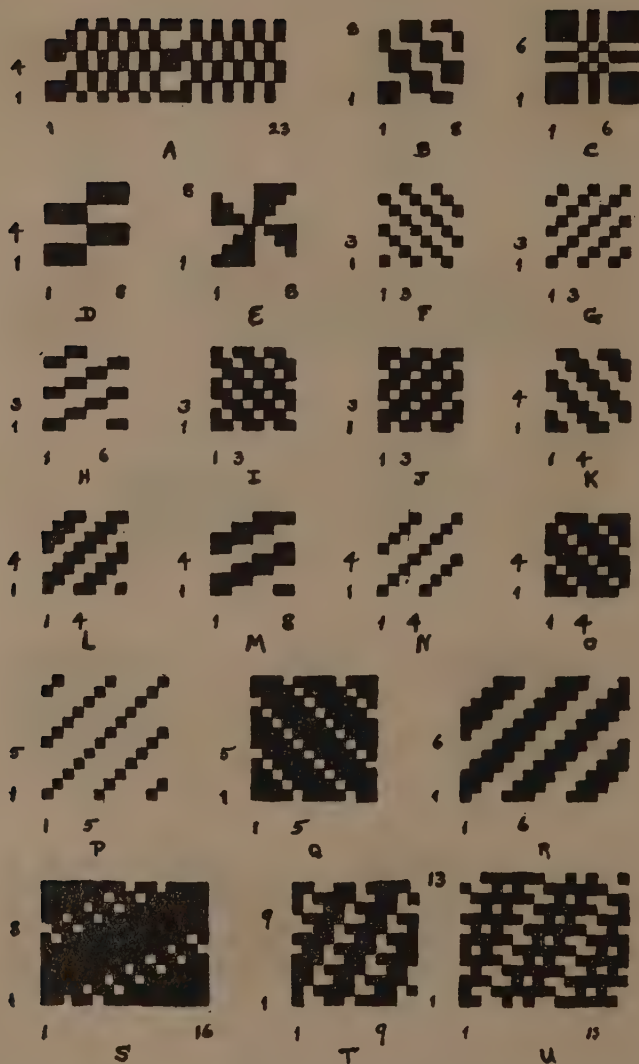
H.	Double warp twill weave	
I.	2/1 Left twill weave	
J.	2/1 Right twill weave	
K.	2/2 Left twill weave	
L.	2/2 Right twill weave	
M.	Double warp twill weave	
N.	1/3 Right twill weave	

O.	3/1 Left twill weave	
P.	1/4 Right twill weave	
Q.	4/1 Left twill weave	
R.	3/3 Right twill weave	
S.	Merveilleux	
T.	Poiret twill	
U.	Tricotine	

Fig. 3.

A. Whipcord
B. Skip twill
C. Charmeen
D. Cantoon weave
E. Mackinaw
F. Mayo twill weave

G. Shoe cloth
H. Velour
I. Rice weave
J. 1/4 Satin weave
K. Haircloth upholstery
L. 4/1 Satin weave

M. 1/5 Irregular satin weave
N. 6/1 Satin weave
O. 7/1 Satin weave
O. 7/1 Satin weave
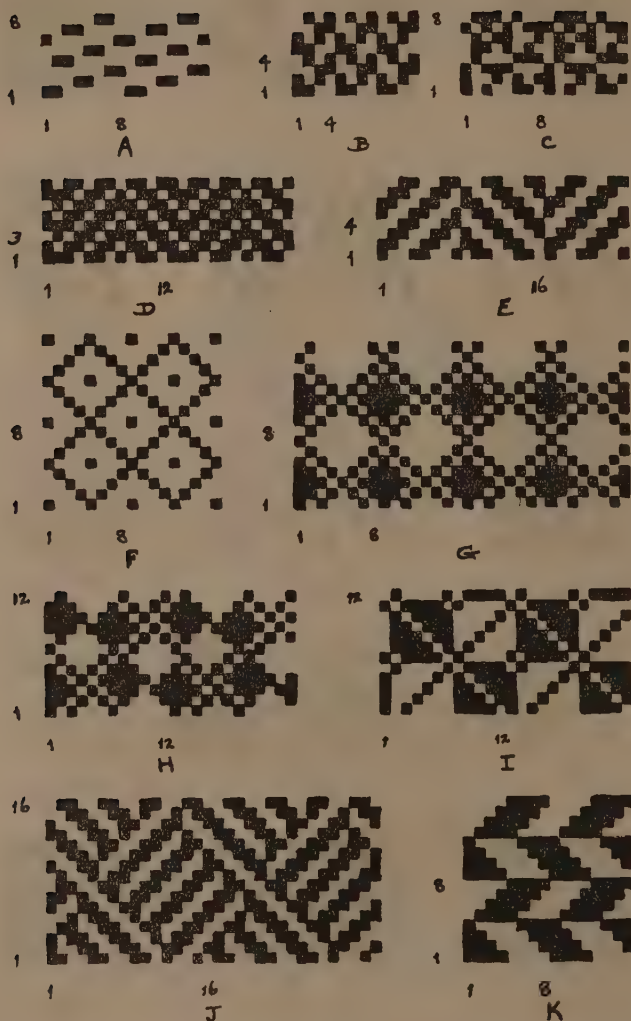
Fig. 4.

A.	Imperial sateen	E.	Tweed	I.	Figured twill
B.	Chain filter cloth	F.	Birdseye	J.	Entwining twill
C.	Pebble cloth	G.	Honeycomb	K.	Tape
D.	Coutil	H.	Brighton cloth		

Fig. 5.

A. Beaver cloth
B. Frieze
C. Gros grain satin
D. Satin royal

E. Blanket, Jacquard
F. Silence cloth
G. Fiber fabric
H. Moleskin

I. Tuck cloth*
J. Molleton
K. President weave

* X represents tuck warp

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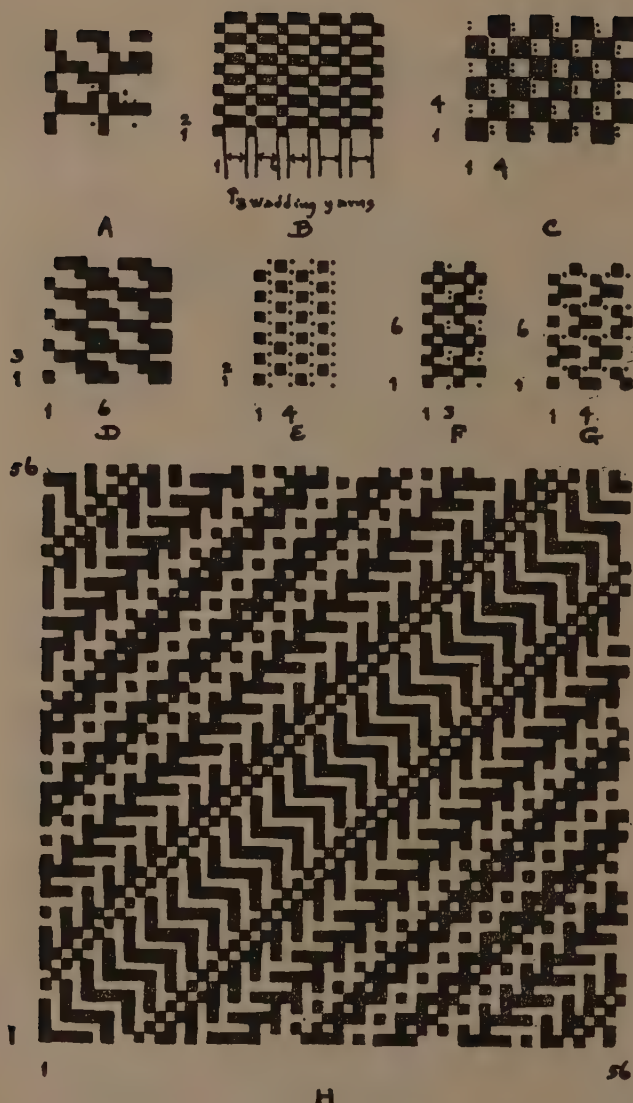
Fig. 6.

A. Frisé*
B. Moquette
C. Plush, upholstery
D. Terry cloth
E. Velours
F. Velvet, chiffon
G. Velvet, cut
H. Whitney

* Dots represent tufts of pile.

Fig. 7.

A. Bolivia*   D. Montagnac   G. Piqué
B. Chinchilla   E. Velveteen
C. Corduroy   F. Mitcheline

* Dots represent tufts of pile.

PLATE I

FIG. A. Ribbonzine   FIG. F. Curved twill
FIG. B. Chamoisette   FIG. G. Alhambra
FIG. C. Astrakhan   FIG. H. Brocatelle
FIG. D. Armure   FIG. I. Compound damask
FIG. E. Figured denim
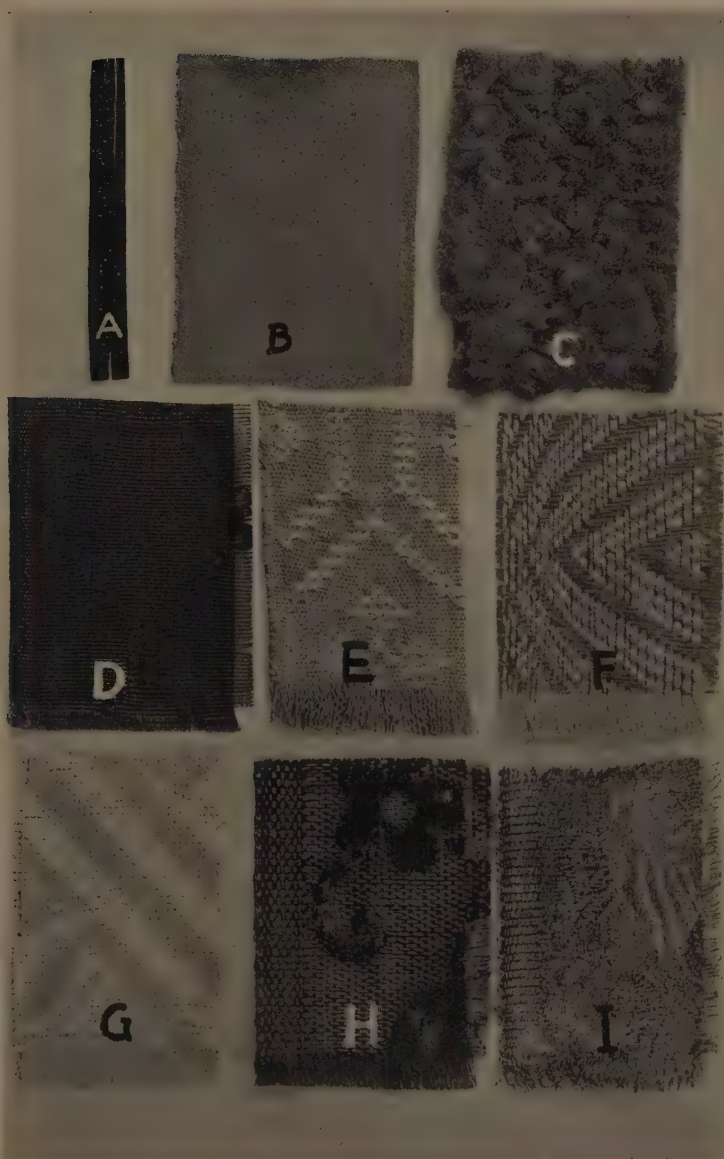
Plate I

PLATE II

FIG. A. Braid
FIG. B. Wicking
FIG. C. Padding
FIG. D. W l jersey
FIG. E. Balbriggan

FIG. F. Bobbinet
FIG. G. Filet
FIG. H. Barred muslin
FIG. I. Madras shirting

Plate II
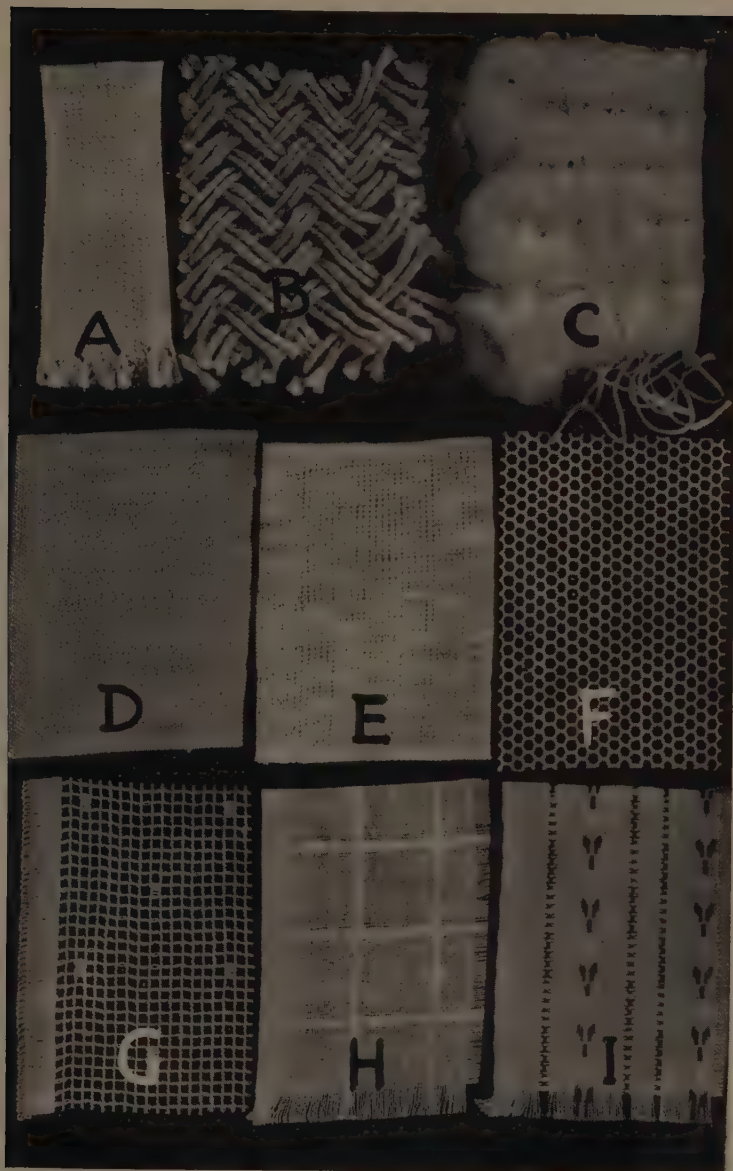
PLATE III

FIG. A. Swiss, lappet dot
FIG. B. Swiss, swivel dot
FIG. C. Swiss, tissue dot
FIG. D. Willow
FIG. E. Fleece-back piqué

FIG. F. Kidderminster cloth
FIG. G. Marseilles
FIG. H. Bagging, gauze
FIG. I. Bolting cloth

Plate III
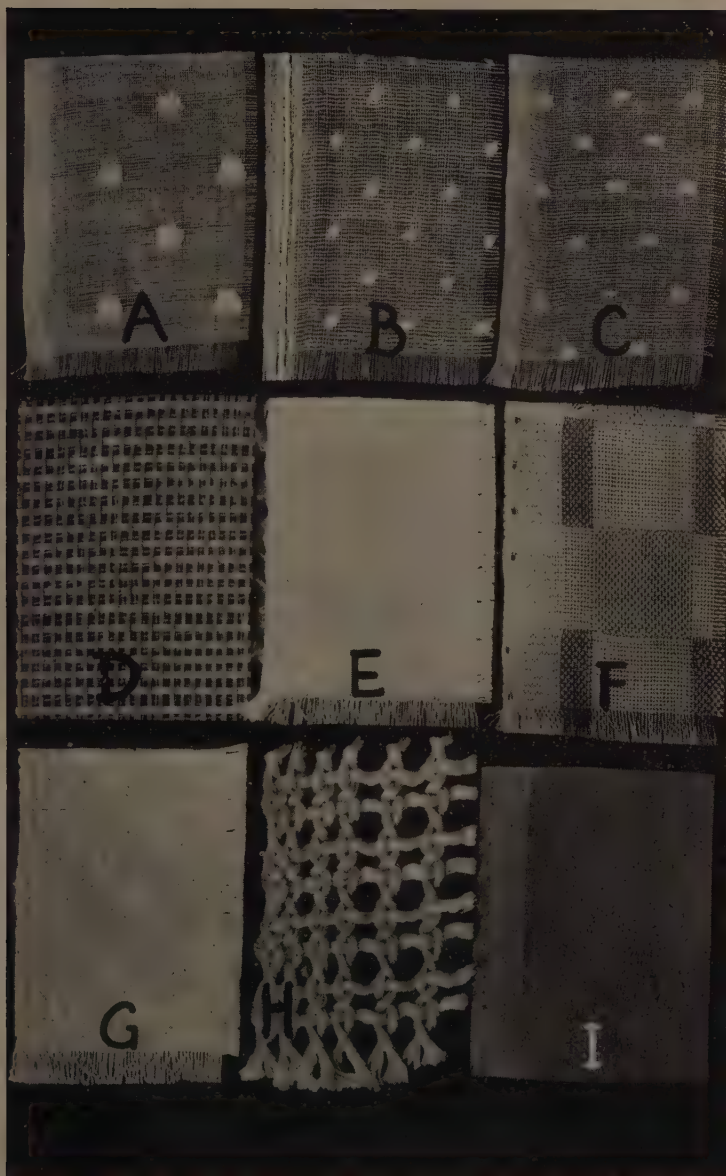
PLATE IV

FIG. A.	Buckram	FIG. E.	Warp ondulé
FIG. B.	Tapestry, upholstery	FIG. F.	Lace Cloth
FIG. C.	Matelassé	FIG. G.	Madras gauze
FIG. D.	Albert cloth	FIG. H.	Russian-Cord shirting

Plate IV
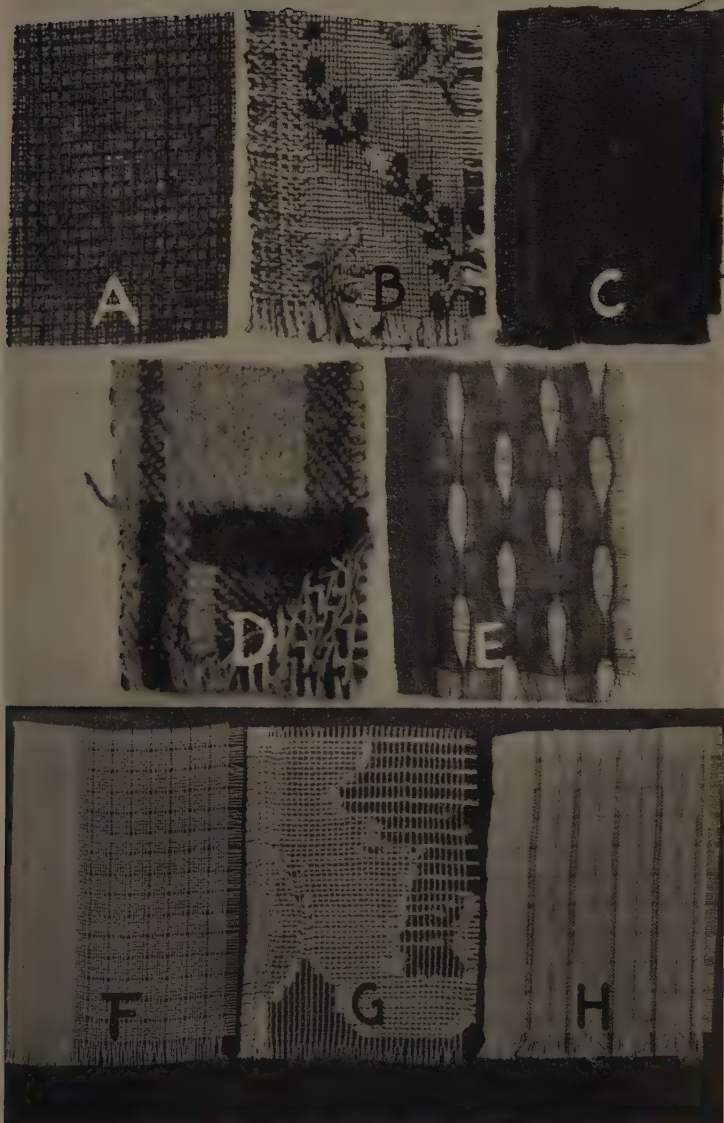
ON THE CHI-SQUARE TEST FOR HOMOGENEITY

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The usual practice among experimental workers, whose data are interpreted in terms of probabilities for or against an event, has been to regard the mean probability as representative of the entire set. If, however, the data are of such a nature that they may be divided for examination into subsets, the likelihood may be determined that the series of subsamples has been drawn from a population which is homogeneous in the sense that the probability of the event is uniform throughout the experimental material. Particularly numerous are those sets of experimental results in which the frequencies of the observations comprising the various subsets are unequal. Among the cases of this kind which have been brought to the attention of the senior author were many dealing with mortalities in induced epidemics of laboratory animals and in controlled infestations of field crops. While the appropriate analysis is in principle directed towards an examination into the homogeneity of the statistical results of the experimentation, in practice it becomes a critical test both of the uniformity of the experimental material and also of the technique employed in handling it.

Let us assume a series of similar treatments of a given population, as of groups of laboratory animals subjected to an infection with a fixed number of pathogenic bacteria, the analysis then resolves itself into a test as to whether the mortalities of the various subsamples are distributed around their mean in such a manner that the deviations therefrom may or may not be ascribed to the chances of random sampling. If an examination shows that the discrepancies from a binomial distribution are so great that they cannot be accounted for on the basis of chance deviations from the expected, it is clear that one or more disturbing factors were present in the experiment. Either the technique (using the term to include all the factors other than those inherent in the experimental subjects) was at fault, or the cause of the departure from expectancy should be sought within the experimental population.

Biological literature contains several examples of analyses of experimental data in which the sizes of the various subsamples are equal. Parkes (1923) compared the actual divergence with the expected under a binomial distribution of the sex-ratio in swine, using records of herdbooks of various breeds, and finding the samples non-homogeneous for this character. McPhee (1927) employed data from an experimental herd of swine which were found to be homogeneous as to sex-ratio. He attributed the heterogeneity of Parkes' data to errors in reporting the distribution of the sexes in the litters. "Mathetes" (1927) in an analysis of the effect of manuring on the infestation of barley by the gout fly gave a very excellent example of the method of procedure when the number of subsets is small.

The limits of laboratory possibilities, however, do not always permit the use of subsets of equal size over a series of experiments. In such cases

a modification of the method of analysis is required. Pearson (1911) and Arne Fisher (1922) have given solutions of the problem. The senior author (1930) has developed a method which is especially adapted to the kinds of data frequently appearing in immunity tests. This method has been adopted by R. A. Fisher (1932) in his fourth edition. The computations will be explained in detail in connection with the first and fourth illustrations to follow.

The data in table 1 are drawn from experiments by the junior author (Irwin, 1929), in which controlled doses of a specific organism were injected into groups of laboratory animals. The sizes of these groups (subsamples) were dictated by the number of experimental animals available

TABLE 1. *Results obtained from injection of fifteen subsamples of a population of rats with a standard dose of the Danysz bacillus*

Subsample number	Number injected n	Number dead s	Percentage mortality p
1	40	31	77.50000
2	12	10	83.33333
3	22	19	86.36364
4	26	22	84.61538
5	43	36	83.72093
6	25	21	84.00000
7	17	14	82.35294
8	20	17	85.00000
9	11	10	90.90909
10	37	35	94.59459
11	39	35	89.74360
12	47	47	100.00000
13	29	22	75.86207
14	43	31	72.09302
15	20	15	75.00000
	$\Sigma n = 431$	$\Sigma s = 365$	$\bar{p} = 84.68678$ per cent
$\bar{q} = 15.31322$ per cent		$\chi^2 = 22.62$	$P = 0.07$

at each date of injection. In any subsample the probability of death is given by

$$p = \frac{100s}{n} \text{ per cent.}$$

The average (weighted mean) probability for the entire sample is

$$\bar{p} = \frac{100 \ \Sigma s}{\Sigma n} \text{ per cent,}$$

while the average probability of survival is

$$\bar{q} = 100 - \bar{p} \text{ per cent.}$$

The problem is to test the hypothesis of homogeneity in the reaction of these groups of rats to the injection. The formula for chi-square is

$$\chi^2 = \frac{100 \ (\Sigma sp - \bar{p} \ \Sigma s)}{\bar{p}\bar{q}}$$

in which Σsp, the sum of the products of the pairs of numbers in the third

and fourth columns of the table, is readily computed on a calculating machine as follows,

$$\Sigma sp = (31)\ (77.50000) + (10)\ (83.33333) + \ldots = 31{,}203.95.$$

Substituting in the formula for chi-square this and the other specified values taken from the table, we have

$$\chi^2 = \frac{100\,[31{,}203.95 - (84.68678)\,(365)\,]}{(84.68678)\,(15.31322)} = 22.62.$$

The test is completed by entering a table of chi-square with degrees of freedom, $15 - 1 = 14$, and noting the probability, $P = 0.07$, that similar samples of chi-square, drawn at random from the same homogeneous population, would be larger. Though this is a rather small probability, still the several inoculated groups may be considered tentatively as subsamples drawn from a population in which a uniform probability of death is regnant. Within the limits of experimental error the animal population may for the present be assumed homogeneous and the technique adequate.

The number of decimal places carried in the table is necessitated by the difference in the numerator of the chi-square fraction. Frequently the first four or five figures cancel out. This would leave the value of chi-square depending upon spurious arithmetic unless an adequate number of decimals is carried.

The chi-square test is frequently capable of extension to greater numbers of observations on account of the well known additive character of the statistic. This obviates the unreliability of small samples while preserving the individuality of the probability which may be inherent in each such sample. The method is illustrated by the data of table 2, the fourth sample in which is the same as that given more in detail in table 1. Each of the

TABLE 2. *Data on five samples of rats inoculated with different doses of the organism*

Dose millions	Number injected	Number of groups	Degrees of freedom	χ^2	P
4000	80	7	6	7.67	0.27
275	134	5	4	8.55	0.08
210	93	3	2	4.44	0.11
150	431	15	14	22.62	0.07
120	102	4	3	2.41	0.39
Totals	34		29	45.69	0.025

populations corresponding to these five samples, if considered alone, would be adjudged homogeneous. All of the samples, however, have values of P lying much closer to the value $P = 0.05$ than to the value $P = 0.95$. Since the five groups of rats were inoculated with different numbers of organisms, they cannot be combined into a single sample of 34 subsets, but it is proper to add the values of chi-square in the several samples, together with their degrees of freedom. This produces a combined experience based on 29 degrees of freedom, with the corresponding values of $\chi^2 = 45.69$ and $P = 0.025$. We conclude that, while this value of chi-square might indeed arise in the process of sampling from a homogeneous population, yet coupled with the consistently small values of P, the presumption is that the probability of death really does vary somewhat from subsample to subsample within each of the five samples, including probably that of table 1. The

increasing certainty in the larger sample is the result of the recurrence of
the small probabilities in the successive small samples.

The value of the foregoing analysis in interpreting the results of ex-
periments in genetics is illustrated by a third set of data (table 3) drawn
from the same source as that of tables 1 and 2. S represents a susceptible

TABLE 3. *Result of inoculating stocks of differing hereditary composition*

Stocks	Number subsamples	Number injected	Number dead	Percentage mortality	χ^2	P
S	46	228	211	92.5	101.7	< 0.01
Ra	15	431	365	84.7	22.6	0.07
R_1	23	137	58	42.3	58.8	< 0.01
F_1	32	175	96	54.9	97.9	< 0.01
B	24	163	81	49.7	57.1	< 0.01
F_2	28	200	51	25.5	71.4	< 0.01

strain, which in combination with Ra (random stock) was used as control
throughout the experiment; R_1, a resistant stock; F_1, the progeny of mat-
ings between individuals of R_1 and S stocks; the backcross, B, and F_2 stocks
are the progeny of matings F_1 X S and F_1 X F_1, respectively.

The percentage mortalities of the backcrossed and F_2 stocks as shown
in table 3 would indicate a dominant factor as determining hereditary re-
sistance to the infection. This would necessitate and strengthen the assump-
tion that the mortalities of the F_1 stock were due to the absence of the
dominant factor; a very logical conclusion since the average reaction of
this hybrid stock was much closer to that of its resistant parent than to
that of the susceptible parent.

However, if each of the stocks be examined by subsets (litters, except
in Ra) according to the method outlined above, it becomes apparent that
one cannot reason from the point of view of averages alone since they in
themselves give no indication as to the homogeneity of the experimental
material. The values of chi-square show clearly that the only stock which
might be said to be drawn from a population homogeneous in regard to
mortality was the Ra (control) stock. In all the other strains the signifi-
cantly large values of chi-square point to variations among the percentage
mortalities in the litters greater than can be accounted for by the chances
of random sampling from a homogeneous population. This means that
there is no evidence for a constant probability of death underlying all the
subsamples of a stock.

If we accept the reaction of the Ra strain as tentative evidence of the
uniformity of technique throughout the experiment, it would seem reason-
able to conclude (disregarding the possibility of other disturbing factors)
that the variability of the other stocks was due to differences inherent with-
in the litters. This is suggestive of parental differences in ability to trans-
mit resistance to offspring. Whatever the cause of the heterogeneity, any
argument for a pair of hereditary factors in determining resistance or
susceptibility in this experiment is shown by this test to have no foundation.

Were there no comparative basis from which to estimate whether or
not the deviations from a binomial distribution might be due to errors of
technique, or to differences in the reactions of the experimental subjects
because of changing environment, it would follow that no critical argument
could be advanced as to whether or not the discrepancies from the expected
under a binomial distribution were due to known causes.

In table 4 we give another example of the advantage of testing for homogeneity before proceeding with further statistical analysis. These data, due to Hartzell (1929), are taken from an experiment designed to test the efficacy of two methods of applying insecticides. The apples were picked from eight trees in each plot.

TABLE 4. *Codling moth injury on two plots with different treatment*

Sprayed plot Lime sulfur and arsenate of lead			Dusted plot 90-10 sulfur arsenate of lead dust		
No. apples examined	No. apples injured	Percentage injured	No. apples examined	No. apples injured	Percentage injured
1804	102	5.65	1083	118	10.90
1811	88	4.86	1011	48	4.75
860	2	0.23	946	128	13.53
1671	7	0.42	840	37	4.41
1078	11	1.02	2347	41	1.75
1204	9	0.75	2404	69	2.87
1199	17	1.42	2548	38	1.49
2149	13	0.60	2376	38	1.60
11776	249	2.114	13555	517	3.814
$\chi^2 = 257$,		$P = 0$	$\chi^2 = 497$,		$P = 0$

The values of χ^2 indicate that there is no constant probability of injury under either method. The difference between the (weighted) mean percentages,

$$3.814 - 2.114 = 1.700 \text{ per cent}$$

may indeed be due to the difference in treatment, but, on the other hand, it may be due to the unknown causes which produce the heterogeneity within the two samples. Under such circumstances, a test for the significance of this difference is of doubtful value. If, however, one desires to make it, he is limited in his choice of a method. He may not use the value of $\bar{p}$ in Pearson's formula (1907) because this has just been proved to have no uniform value in the subsamples. If he should use the chi-square test for independence in the ordinary fourfold table, he would ignore the demonstrated heterogeneity of the subsets. Since he is dealing with small samples, the appropriate method is that of Fisher (1932). For this the sum of the squares of deviations from mean is required in each plot. These are easily obtained from the formula for the weighted variance in such tables as 1 and 4,

$$\sigma^2 = \frac{100 \, (\Sigma sp - \bar{p} \Sigma s)}{\Sigma n}.$$

Since the numerator is the same as that of the chi-square fraction, the additional computation is trivial. The variances in the two plots of apple trees are

$$\sigma_1^2 = 4.5104 \text{ and } \sigma_2^2 = 13.4542.$$

From these, the desired sums of squares are derived simply by multiplication by eight, the number of subsamples in each plot. Using Fisher's method of computation the following table is obtained.

	Number of trees, N	Degrees of freedom	Variance, σ^2	Sum of squares, $N\sigma^2$
Sprayed plot	8	7	4.5104	36.083
Dusted plot	8	7	13.4542	107.634
Totals		14		143.717

Pooled estimate of variance $= \dfrac{143.717}{14} = 10.265$.

Variance of mean difference $= 10.265 \ (\frac{1}{8} + \frac{1}{8}) = 2.566$.

Standard deviation of mean difference $= \sqrt{2.566} = 1.602$ per cent.

$$t = \frac{1.700}{1.602} = 1.061. \qquad P = 0.3.$$

The conclusion is that the difference between the percentages of apples injured in the two plots is too small to be attributed to anything other than chance variations in subsamples from the same population. The lack of homogeneity may be due either to the technique of applying the insecticide or to some unknown characteristics of the onslaught of the insects. No critical test of treatment is possible in the presence of such pronounced heterogeneity in the percentage of injured fruits.

SUMMARY

A test of technique is outlined for experiments whose results are expressed as probabilities for or against an event in groups of unequal frequencies.

Examples are given of the manner in which the application of the test may enable the investigator to avoid erroneous conclusions if heterogeneity appears.

For the case of unequal frequencies an efficient method of computation of chi-square and standard deviation is explained in detail.

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A CATALOG AND HOST-INDEX OF THE SPECIES OF THE COCCIDIAN GENUS EIMERIA

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The frequency with which new species of coccidia of the genus Eimeria are being described and the widely scattered literature on the subject make desirable a catalog of the species described to date. In an effort to compile such a catalog the original literature has been consulted in most cases, but in a few instances, indicated in the bibliography, it was necessary to rely upon the statements of other authors who apparently had their information directly from the original descriptions.

While a sincere effort has been made to include in the catalog both those species which have been described under the generic name Eimeria and species described under other generic names, but very plainly to be included in Eimeria, it is nevertheless possible that a few species have been overlooked. Hence the catalogers invite correspondence from workers who may have noted any such omissions.

The effort has been made to confine activities within the proper sphere of the cataloger. Homonyms have been indicated by footnotes. Certain species which were originally assigned to the genus Eimeria, but which for very evident reasons appear actually to have no proper place in this genus, have been retained in the catalog, but in these cases footnotes have been inserted to indicate their true genera. No decisions have been made concerning synonyms. The reason for this should be apparent to workers familiar with the difficulties involved, in innumerable cases, in definitely resolving questions of synonymy.

In some instances authors have described species as "Eimeria (?)" or "Genus (?)", stating in the latter case that the species may be Eimeria. These have been retained in the catalog, the footnote "Genus (?)" being used to designate them. There are listed 220 species and 183 hosts.

GENUS EIMERIA AIMÉ SCHNEIDER 1875

Synonymy

> *Cytospermium* Rivolta 1878
> *Coccidium* Leuckart 1879
> *Orthospora* Schneider 1881
> *Karyophagus* Steinhaus 1889
> *Pfeifferia* Labbé 1894
> *Bananella* Labbé 1895
> *Goussia* Labbé 1896
> *Crystallospora* Labbé 1896
> *Pfeifferella* Labbé 1899
> *Eimeriella* Stiles 1901
> *Paracoccidium* Laveran & Mesnil 1902
> *Jarrina* Léger & Hesse 1922

CATALOG OF SPECIES OF EIMERIA

Following each species (listed alphabetically) is the name of the individual or individuals who described the species, together with the year of publication. The citations will be found at the end of the article. Where an author published more than one pertinent article in a single year, the papers are designated as (a), (b), etc. Next is given the size of the oocyst measured in microns, (R) designating range of size and (M) the mean. Next follows the scientific name of the host, and the common name, when known.

Eimeria acanthodactyli (Phisalix, 1930). (M) 31.5 x 21.
  In *Acanthodactylus scutellatus,* Fringe-toed lizard.
E. acervulina Tyzzer, 1929. (R) 17.7-20.2 x 13.7-16.3. (M) 19.5 x 14.3.
  In *Gallus domesticus,* Domestic fowl and *Colinus virginianus virginianus,* Bobwhite.
E. aemula Yakimoff, 1931 (a). (R) 20.4-36.0 x 17.0-25.5. (M) *circa* 26.8 x 20.4.
  In *Ovis aries,* Domestic sheep.
E. agamae (Laveran & Pettit, 1910). (R) 20-25 x 11-14.
  In *Agama colonorum,* Lizard.
E. alburni (Stankovitch, 1920). (R) 19-20.
  In *Cyprinus gobio,* Whitefish; *Leuciscus rutilus,* Common roach; and *Scardinius erythrophthalmus,* Red roach.
E. amarali Pinto, 1928 (a).
  In *Bothrops neuwiedii,* Snake.
E. anguillae Léger & Hollande, 1922. (M) 10.
  In *Anguilla vulgaris,* Eel.
E. anseris Kotlán, 1932. (R) 11-16; 22.
  In *Anser anser,* Goose.
E. arctomysi Galli-Valerio, 1931. (M) 24 x 20.
  In *Arctomys marmota,* Marmot.
E. arloigni (Marotel, 1905). (M) 25 x 17.
  In *Capra hircus,* Domestic goat.
E. arnaldoi Pinto & Maciel, 1929. (R) 30 x 14-15.
  In *Tamnodynastes strigilis,* Snake.
E. arvicolae (Galli-Valerio, 1905). (R) 14-18 x 14-18.
  In *Arvicola nivalis,* Fieldmouse.
E. avium (Rivolta, 1878).
  In *Gallus domesticus,* Domestic fowl; and other birds.
E. azerbaidjhanaica Yakimoff, 1933. (M) 45.0 x 21.6.
  In *Buffelus bubalus,* Buffalo.
E. beachi Yakimoff & Rastegaïeff, 1931. (R) 12.75-22.10. (M) 16.79.
  In *Gallus domesticus,* Domestic fowl.
E. beauchampi* Léger & Duboscq, 1917.
  In *Glossobalanus minutus.*
E. beecheyi Henry, 1932. (R) 16.0-22.4 x 12.8-10.2 *(sic).* (M) 19.2 x 16.0.
  In *Citellus beecheyi,* Ground squirrel.
E. belawini Yakimoff, 1929 (b). M) 12.21 x 12.21.
  In *Hyla arborea,* Frog.
E. bigemina (Labbé, 1896). (R) 27-28 (Yakimoff, 1929 a).
  In *Ammodytes tobianus,* Sand eel.
E. bilamellata Henry, 1932. (R) 25.6-35.6 x 22.4-25.6. (M) 32.0 x 25.6.

In *Callospermophilus chrysodeirus,* Golden-mantled ground squirrel.

E. bitis Fantham, 1932. (R) 27.9-36.4 x 17.8-24.3.
In *Bitis arietans,* Puff adder.

E. botelhoi Carini, 1932. (M) 36 x 28.
In *Guerlinguetus ingrami,* Squirrel.

E. boveroi Carini & Pinto, 1926.
In *Hemidactylus mabuia,* Gecko.

E. bracheti Gérard, 1913. (R) 23-24 x 18-19.
In *Gallus domesticus,* Domestic fowl.

E. brodeni Cerruti, 1930. (R) 18-20 x 28-32.
In *Testudo graeca,* Turtle.

E. brumpti Cauchemez, 1921. (R) 13-30 x 9-18.
In *Sus scrofa,* Pig.

E. bukidnonensis Tubangui, 1931. (R) 46.8-50.4 x 33.3-37.8.
In *Bos taurus,* Ox.

E. butkai Causey, 1926.
In *Homo sapiens,* Man.

E. callospermophili Henry, 1932. (R) 16.0-22.4 x 16.0-22.4 (*sic*). (M) 19.2 x 16.0.
In *Callospermophilus chrysodeirus,* Golden-mantled ground squirrel.

E. canis Wenyon, 1923. (R) 18-45 x 11-28.
In *Canis familiaris,* Dog.

E. canna Triffitt, 1924. (R) 23.5-34 x 16.5-20.
In *Orias canna,* Eland.

E. capreoli Galli-Valerio, 1927. (M) 24 x 13.
In *Cervus capreolus,* Roe (Deer).

E. carinii Pinto, 1928 (b). (R) 22-23.8.
In *Mus norvegicus,* Norway rat.

E. carpelli Léger & Stankovitch, 1921. (R) 13-14.
In *Cyprinus carpio,* Carp.

E. cati Yakimoff, 1933. (M) 20.8 x 17.1; 18 x 18.
In *Felis domestica,* house-cat.

E. caucasica Yakimoff & Buewitsch, 1932. (R) 25.2-36.0 x 14.4-21.6. (M) 32.7 x 19.0.
In ''Berghühnern.''

E. caviae Sheather, 1924. (R) 17-25 x 13-18.
In *Cavia cobaya,* Guinea pig.

E. cerastis (Chatton, 1912). (M) 40 x 20.
In *Cerastes cornutus* and *Cerastes vipera,* Snakes.

E. cervi Galli-Valerio, 1927. (M) 35 x 21.
In *Cervus elaphus,* Stag.

E. citelli Kartchner & Becker, 1930. (R) 15-23 x 14-19. (M) 18.8 x 15.8.
In *Citellus tridecemlineatus,* Ground squirrel.

E. clini Fantham, 1932. (R) 13.6-17.7 x 11.8-15.
In *Clinus superciliosus,* Klip-fish.

E. clupearum (Thélohan, 1894). (R) 18-21.
In *Clupeus harengus,* Herring; *Clupeus pilchardus,* Sardine; *Engraulis encrasicholus,* Anchovy; and *Scomber scomber,* Mackerel.

E. cobitis Stankovitch, 1923. (R) 19-21.
In *Cobitis taenia,* Fish.

E. coelopeltis (Galli-valerio, -1926) (*V*. Hoare, 1933) (M) 10.5 x 6.0.
    In *Coelopeltis lacertina,* Snake.
E. cotti Gautier, 1921. (R) 10-11.
    In *Cottus gobio,* Bull-head.
E. cristalloides (Thélohan, 1894). (R) 20-25.
    In *Motella fusca, M. maculata,* and *M. tricirrata,* Fish.
E. crotalae Phisalix, 1919. (M) 32 x 22.
    In *Crotalus terrificus,* Rattlesnake.
E. cruciata Thélohan, 1892. (M) 25 x 25.
    In *Caranx trachurus,* Horse mackerel.
E. cuniculi (Rivolta, 1878).
    In *Lepus cuniculus,* Rabbit.
E. cylindrica Wilson, 1931. (R) 19.4-26.8 x 11.9-14.9. (M) 23.3 x 13.3.
    In *Bos taurus,* Ox.
E. cylindrospora Stankovitch, 1921. (R) 10-11.
    In *Alburnus lucidus,* Fish.
E. cynomysis Andrews, 1928. (R) 33-37 x 28-32. (M) 35.36 x 30.04.
    In *Cynomysis ludovicianus,* Prairie dog.
E. cyprini Plehn, 1924. (M) 9 (Yakimoff 1929 a).
    In *Cyprinus carpio,* Carp; and *Tinca vulgaris,* Tench.
E. cyprinorum Stankovitch, 1921. (R) 12-13.
    In *Barbus fluviatilis, Leuciscus rutilus, Phoxinus laevis,* and
    Scardinius erythrophtalmus, Fish.
E. cystis-felleae Debaisieux, 1914. (R) 30-38 x 20-25.
    In *Tropidonotus natrix,* Snake.
E. debliecki Douwes, 1921. (M) 24 x 18.
    In *Sus scrofa,* Pig.
E. delagei (Labbé, 1893) (a). (R) 20-22 x 16-17.
    In *Cistudo europaea,* Box tortoise.
E. dispersa Tyzzer, 1929. (R) 17.16-26.4 x 15.44-22.44. (M) 22.75 x 18.84.
    In *Colinus virginianus virginianus,* Bob-white; and *Phasianus*
    colchicus torquatus, Ring-necked pheasant.
E. dispersa (slow develeeping variety) Tyzzer, 1929. (R) 19.8-27.06 x
    16.5-20.46. (M) 23.89 x 18.05.
    In *Colinus virginianus virginianus,* Bob-white.
E. dukei Lavier, 1927 (R) spherical form 20-24. (R) oval form 23-25 x
    18.5-22.
    In *Nyctinomus pumilus,* Bat.
E. ekdysios Triffitt, 1928. (R) 19-40 x 12-25.
    In *Tachypodoiulus niger,* Millipede.
E. elegans Yakimoff, Gousseff & Rastegaïeff, 1932. (R) 23.4-37.8 x 18.0-23.4.
    (M) 34.2 x 19.8.
    In *Gazella subgutturosa,* Persian gazelle.
E. ellipsoidalis Becker & Frye, 1929. (R) 20-26 x 13-17. (M) 23.4 x 15.9.
    In *Bos taurus,* Ox.
E. epidermica* Léger & Duboscq, 1917.
    In *Glossobalanus minutus.*
E. escomeli* Rastegaïeff, 1930. (M) oval form 20.7 x 17.1. (M) round
    form 18.0.
    In *Myrmecophaga trigaetyla,* Ant-eater.
E. falciformis (Eimer, 1870). (M) 26 x 16 (Rastegaïeff, 1930).
    In *Mus musculus,* Mouse.

E. falciformis var. *criceti* Nöller, 1920. (R) 18-22 x 11.
    In *Cricetus cricetus,* Hamster.
E. faurei (Moussu & Marotel, 1901). (R) 30-40 x 18-26.
    In *Ovis aries* and *O. musimon,* Sheep.
E. felina Nieschulz, 1924. (R) 21-26 x 13-17. (M) 24 x 14.5.
    In *Felis domestica,* Domestic cat; and *Felis leo,* Lion.
E. furonis Hoare, 1927. (R) 11.2-14.4 x 10.4-12.8. (M) 12.8 x 12.0.
    In *Putorius putorius* var. *furo,* Ferret.
E. gadi Fiebiger, 1913. (R) 26-28 Yakimoff, 1929 a).
    In *Gadus aeglefinns, G. morrhua,* and *G. virens,* Fish.
E. galli-valerioi Rastegaïeff, 1930. (R) 16.20-22.75 x 10.8-14.4.
    In *Cervus elaphus,* Stag.
E. galouzoi Yakimoff & Rastegaïeff, 1930 (a). (R) 19.8-21.0. (M) 20.4.
    In *Capra hircus,* Domestic goat.
E. gasterostei (Thélohan, 1890). (R) 16-18.
    In *Gasterosteus clupeatus,* Fish.
E. gekkonis Tanabe, 1928.
    In *Gekko japonicus,* Gecko.
E. geomydis Skidmore, 1929. (R) 11.6-14.9 x 11.6-13.3. (M) 13.3 x 12.5.
    In *Geomys bursarius,* Pocket gopher.
E. gigantea Labbé, 1894 (a). (M) 70 x 40 (Labbé, 1896).
    In *Lamna cornubica,* Shark.
E. globosa (Labbé, 1893) (c). (R) 16-24.
    In *Gallus domesticus,* Domestic fowl.
E. gobii Fantham, 1932. (R) 16.8-20.8 x 12.8-16.
    In *Gobius nudiceps,* Dikkop (Fish).
E. grobbeni Rudovsky, 1925.
    In *Salamandra atra,* Salamander.
E. gubleri (Guiart, 1922).
    In *Homo sapiens,* Man.
E. hagenmülleri Léger, 1898.
    In *Stigmatogaster gracilis,* Myriapod.
*E. hartmanni** Rastegaïeff, 1930. (M) 22.75 x 14.4.
    In *Felis tigris,* Tiger.
E. hegneri Rastegaïeff, 1930. (R) 16.2-18.0 x 10.8-14.4.
    In *Cervus canadensis,* Wapiti.
E. hessei Lavier, 1924. (R) 16-20.
    In *Rhinolophus hipposideros,* Bat.
E. hirsuta Schneider, 1887. (M) 25 (Labbé, 1899).
    In *Gyrinus natator,* Whirligig beetle.
E. hominis¶ (Rivolta, 1877).
    In *Homo sapiens,* Man.
E. hyalina (Léger, 1898).
    In *Coleoptera* gen. ?, Beetle.
E. ictidea Hoare, 1927. (R) 18.4-27.2 x 12.8-20.8. (M) 23.6 x 17.5.
    In *Putorius putorius* var. *furo,* Ferret.
E. intricata Spiegl, 1925. (M) 45.6 x 33.0.
    In *Ovis aries,* Sheep.
E. irresidua Kessel & Jankiewicz, 1931. (M) 38.3 x 25.6.
    In *Lepus cuniculus,* Rabbit.
E. jalina† Perroncito, 1901.
    In *Sus scrofa,* Pig.

E. jalina‡ (Krediet, 1921).
>   In *Sus scrofa,* Pig.

E. johnsoni Yakimoff & Rastegaïeff, 1931. (R) 15.93-27.50 x 14.20-20.40.
>   (M) 21.89 x 17.80.
>   In *Gallus domesticus,* Domestic fowl.

E. kermorganti (Simond, 1901) (a).
>   In *Gavialis gangeticus,* Gavial.

E. labbeana Pinto, 1928 (c). (R) 16-18.
>   In *Columba livia,* Domestic pigeon.

E. lacazei (Labbé, 1895). (R) 35-40 x 30-35.
>   In *Lithobius forficatus,* Centipede.

E. lagopodi Galli-Valerio, 1929. (M) 24 x 15.
>   In *Lagopus mutus,* Ptarmigan.

E. legeri (Simond, 1901) (b).
>   In *Emyda granosa,* Soft tortoise.

E. legeri‡ (Stankovitch, 1920). (M) 10.
>   In *Alburnus brama,* Bream; *A. lucidus,* Small Bleak; and *Scardinius erythrophtalmus,* Red roach.

E. leporis Nieschulz, 1923. (R) 26-38 x 13-20. (M) 32 x 16.
>   In *Lepus timidus,* Alpine hare.

E. leptodactyli Carini, 1931 (a). (M) 20 x 17.
>   In *Leptodactylus ocellatus,* Frog.

E. lucida (Labbé, 1893). (R) 10-11.
>   In *Acanthias vulgaris,* Spiny dog-fish; *Mustellus vulgaris,* Shark; and *Scyllium catulus,* Dog-fish.

E. lyruri Galli-Valerio, 1927. (R) 24-27 x 15.
>   In *Lyrurus tetrix,* Black grouse.

E. macropodis Wenyon & Scott, 1925. (R) 22-34 x 10-17.
>   In *Macropus bennettii,* Bennett's wallaby.

E. magna Pérard, 1925. (M) 35 x 24.
>   In *Lepus cuniculus,* Domestic rabbit; and *L. californicus,* Jack Rabbit.

E. marmotae Galli-Valerio, 1923. (M) 51 x 42.
>   In *Arctomys marmota,* Marmot.

E. maxima Tyzzer, 1929. (R) 21.5-42.5 x 16.5-29.8. (M) 29.3 x 22.6.
>   In *Gallus domesticus,* Domestic fowl.

E. media Kessel & Jankiewicz, 1931. (M) 31.2 x 18.5.
>   In *Lepus cuniculus,* Domestic rabbit, and *L. californicus,* Jack rabbit.

E. meleagridis Tyzzer, 1927. (R) 19.14-29.7 x 14.52-23.1. (M) 23.79 x 17.33 (Tyzzer, 1929).
>   In *Meleagris mexicana,* Domesticated turkey.

E. meleagrimitis, Tyzzer, 1929. (R) 16.5-20.46 x 13.2-17.23. (M) 18.12 x 15.28.
>   In *Meleagris mexicana,* Domesticated turkey.

E. melis Kotlán & Pospesch, 1933. (R) 17-24 x 13-17. (M) 19 x 21.
>   In *Meles taxus,* Badger.

E. mephitidis Andrews, 1928. (R) 17-25 x 16-22. (M) 20.68 x 19.24.
>   In *Mephitis mephitica,* Skunk.

E. mesnili Rastegaïeff, 1930. (R) 18.0 x 10.8-16.2.
>   In *Canis lagopus,* Blue fox.

E. metchnikovi (Laveran, 1897). (R) 20-25.
>   In *Gobio fluviatilis,* Gudgeon (Fish).

E. minuta Thélohan, 1892. (R) 9-10.
    In *Tinca vulgaris,* Tench.

E. misgurni Stankovitch, 1923. (R) 15-16.
    In *Cobitis taenia,* Spiny loach; and *Misgurnus fossilis,* Loach.

E. mitis Tyzzer, 1929 (R) 14.3-19.6 x 13.0-17.0. (M) 16.2 x 15.5.
    In *Gallus domesticus,* Domestic fowl.

E. mitraria (Laveran & Mesnil, 1902) (a). (R) 10-15.
    In *Damonia reevesii,* Terrapin.

E. miyairii Ohira, 1912. (R) 16.2-26.4 x 13.4-21.3. (M) 22.5 x 17.8. (Becker *et al.,* 1932).
    In *Mus rattus,* Black rat; and *M. norvegicus,* Norway rat.

E. monacis Fish, 1930. (R) 16.8-23.2 x 15.2-21.1. (M) 19.97 x 18.26.
    In *Marmota monax,* Woodchuck.

E. motellae (Labbé, 1893) (b). (R) 13-14.
    In *Motella tricirrata,* Fish.

E. necatrix Johnson, 1930. (R) 13.2-22.7 x 11.3-18.3. (M) 16.7 x 14.2. (Tyzzer, Theiler, & Jones, 1931).
    In *Gallus domesticus,* Domestic fowl.

E. neglecta Nöller, 1920. (R) 9-10.
    In *Rana esculenta,* Frog.

E. neotomae Henry, 1932. (R) 16.0-22.4 x 12.8-19.2. (M) 22.4 x 16.0.
    In *Neotoma fuscipes,* Wood rat.

E. nepae†† Schneider, 1887.
    In *Nepa cinerea,* Water scorpion.

E. nieschulzi Dieben, 1924.
    In *Mus rattus,* Black rat; and *M. norvegicus,* Norway rat.

E. ninae kohl-yakimov Yakimoff & Rastegaïeff, 1930 (a). (R) 18.9-25.4 x 14.4-21.0. (M) (1) 20.7 x 14.8. (2) 23.0 x 16.1.
    In *Capra hircus,* Domestic goat; and *Ovis aries,* Sheep.

*E. nölleri** Rastegaïeff, 1930. (M) 18.9.
    In *Coelogenus paca,* Paka.

E. novae£ Schneider, 1881.
    In *Glomeris* sp.?, Millipede.

E. novo-wenyoni Rastegaïeff, 1930. (R) 14.4-18.0.
    In *Felis tigris,* Tiger.

E. nuda§ (Marcone, 1908).
    In *Canis familiaris,* Dog.

E. nuttalli Yakimoff & Matikawschwili, 1932. (R) 16.5-23 x 13.2-16. (M) 19.5 x 14.
    In *Procyon lotor,* Raccoon.

E. ondatrae-zibethicae Martin, 1930. (R) 18.75-28.22 x 13.28-26.25. (M) 22.33 x 17.97.
    In *Ondatra zibethica,* Muskrat.

E. os Crouch & Becker, 1931. (R) 20-26 x 18-22.
    In *Marmota monax,* Woodchuck.

E. oviformis (Leuckart, 1879). (R) 33-37 x 15-20.
    In *Lepus cuniculus,* Domestic rabbit.

E. oxyspora Dobell, 1919. (M) 36.
    In *Homo sapiens,* Man.

E. paludosa (Léger & Hesse, 1922). (R) 14-15 x 11.
    In *Fulica atra,* Coot; and *Gallinula chloropus,* Moor-hen.

E. parva Kotlán, Mocsy & Vajda, 1929. (R) 11.4-14.3 x 9.5-11.8.
    In *Ovis aries,* Sheep.

E. percae (Dujaric de la Rivière, 1914).
　　　In *Perca fluviatilis*, Common perch.
E. perforans (Leuckart, 1879).   (M) 22.7 x 14.2.   (Kessel & Jankiewicz, 1931).
　　　In *Lepus cuniculus*, Domestic rabbit; and *L. californicus*, Jack rabbit.
E. perforoides Crouch & Becker, 1931.   (R) 17-24 x 15-20.
　　　In *Marmota monax*, Woodchuck.
E. perichaetae* (Beddard, 1888).
　　　In *Perichaeta armata* and *P. novae-zelandiae*, Annelids.
E. perminuta Henry, 1931.   (R) 11.2-16.0 x 9.6-12.8.
　　　In *Sus scrofa*, Pig.
E. persica (Phisalix, 1925).   (M) 31.5 x 18.9.
　　　In *Tropidonotus natrix* var. *persa*, Snake.
E. pfeifferi Labbé, 1896.
　　　In *Geophilus ferruginosus*, Centipede.
E. pfeifferi‡ (Labbé, 1896).   (R) 16-18.
　　　In *Columba livia*, Domestic pigeon.
E. phasiani Tyzzer, 1929.   (R) 19.8-26.4 x 13.2-17.82.   (M) 23.04 x 15.89.
　　　In *Phasianus colchicus torquatus*, Ring-necked pheasant.
E. pigra Léger & Bory, 1932.   (R) 17-19 x 14.
　　　In *Scardinius erythrophtalmus*, Red roach.
E. pintoi Carini, 1931 (b).   (R) 30-33 x 20-22.
　　　In *Crocodilus* sp. ?, Cayman.
E. piraudi Gautier, 1921.   (R) 11-13.
　　　In *Cottus gobio*, Bullhead.
E. praecox Johnson, 1930.   (R) 19.78-24.72 x 15.66-19.78.   (M) 21.25 x 17.07.   (Tyzzer, Theiler, & Jones, 1931).
　　　In *Gallus domesticus*, Domestic fowl.
E. prevoti (Laveran & Mesnil, 1902) (b).   (R) 20-22 x 12-15.   (usual form).   (M) 18 x 16 (subspherical form).
　　　In *Rana esculenta*, Frog.
E. princeps (Labbé, 1894) (a).
　　　In *Lepus cuniculus*, Rabbit.
E. propria (Schneider, 1881).   (R) 30-36 x 21-30.
　　　In *Molge cristata*, *M. palmata*, and *M. punctata*, Newts.
E. pylori (Gebhardt, 1897).
　　　In *Rana* sp. ?, Frog.
E. pythonis Triffitt, 1925.   (R) 17-36 x 11.5-21.   (M) 27 x 16.
　　　In *Python sebae* and *P. molurus*, Pythons.
E. raillieti (Léger, 1899).   (M) 18.
　　　In *Anguis fragilis*, Blindworm.
E. ranae Dobell, 1908.   (M) 22 x 18.
　　　In *Rana* sp. ?, Frog.
E. ranarum (Labbé, 1894) (b).   (M) 17 x 12.
　　　In *Rana esculenta*, Frog.
E. residua Henry, 1932.   (R) 22.4-28.8 x 19.2-25.6.   (M) 25.6 x 22.4.
　　　In *Neotoma fuscipes*, Wood rat.
E. rivierei Yakimoff, 1929 (a).   (R) 14-16.8 (Round form).   (R) 11.55-15.4 x 7-13.3 (Oval form).
　　　In *Perca fluviatilis*, Perch.
E. rocha-limai Carini & Pinto, 1926.
　　　In *Hemidactylus mabuia*, Gecko.

E. roscoviensis (Labbé, 1893) (d). (R) 16-18 x 14-16.
　　In *Charadrius cantianus, C. philippinus, Strepsilas interpres, Numenius phaeopus, Pluvialis apricarius, Totanus calidris, Calidris arenaria, Pelidna torquata, Tringa alpina, Actitis hypoleucos, Phalacrocorax cristatus,* and *Motacilla alba,* Birds.

E. rouxi Elmassian, 1909. (M) 10.
　　In *Tinca vulgaris,* Tench.

E. rupicaprae Galli-Valerio, 1923. (M) 21 x 16.5.
　　In *Capella rupicapra,* Chamois.

E. salamandrae (Steinhaus, 1889).
　　In *Salamandra maculosa,* Salamander.

E. salamandrae-atrae (Phisalix, 1927). (M) 27.5 x 23.
　　In *Salamandra atra,* Salamander.

E. sardinae (Thélohan, 1890). (M) 50.
　　In *Clupeus pilchardus,* Sardine.

E. scabra Henry, 1931. (R) 22.4-35.6 x 16.0-25.6.
　　In *Sus scrofa,* Pig.

E. scapani Henry, 1932. (R) 16.0-22.4 x 14.4-16. (M) 19.2 x 16.0.
　　In *Scapanus latimanus,* Mole.

E. schaudinniana Pinto, 1928 (c).
　　In *Lithobius forficatus,* Centipede.

E. schneideri Bütschli, 1882.
　　In *Lithobius forficatus,* Centipede.

E. schubergi (Labbé, 1896). (M) 26 x 16.
　　In *Mus musculus,* Mouse.

E. schubergi‡ Schaudinn, 1900.
　　In *Lithobius forficatus,* Centipede.

E. scinci (Phisalix, 1923). (M) 36 x 25.
　　In *Scincus officinalis,* Skink.

E. sciurorum Galli-Valerio, 1922. (M) 24 x 15.
　　In *Sciurus vulgaris* and *Neosciurus carolinensis,* Squirrels.

E. scyllii (Drago, 1902).
　　In *Scyllium* sp.?, Dog-fish.

E. separata Becker & Hall, 1931. (R) 13.1-23.8 x 11.4-18. (M) 18.0 x 14.6.
　　In *Mus norvegicus,* Norway rat, wild and albino.

E. sibirica Yakimoff & Terwinsky, 1931. (R) 21.25-27.62 x 17.0-21.25. (M) 24.25 x 19.45.
　　In *Martes zibellina,* Sable.

E. simondi (Léger, 1898).
　　In *Himantarium gabrielis,* Myriapod.

E. smithi Yakimoff & Galouzo, 1927. (R) 25.2-32.4 x 19.8-28.8. (M) 31.5 x 21.6.
　　In *Bos taurus,* Ox; and *Bison bison,* Bison.

E. snijdersi Dobell, 1920. (R) 40-48.
　　In *Homo sapiens,* Man.

E. soricinae Galli-Valerio, 1927. (M) 50 x 30.
　　In *Sorex vulgaris,* Shrew.

E. soricis Henry, 1932. (R) 19.2-22.4 x 12.8-14.4. (M) 19.2 x 14.4.
　　In *Sorex californicus,* Shrew.

E. soufiae Stankovitch, 1921. (R) 17-18.
　　In *Squalius agassizii,* Fish.

E. southwelli Halawani, 1929. (M) 38 x 12.
　　In *Aëtobatis narinari,* Devil-fish.

E. sp. (Eimer, 1870).
>> In *Lacerta* sp.?, Lizard.

E. sp. Grassi, 1888.   (R) 14-15 (Wenyon, 1926).
>> In *Coronella austriaca*, Snake.

E. sp. Henry, 1932.   (R) 22.4-32.0 x 16.0-19.2.   (M) 28.8 x 19.2.
>> In *Sciurus griseus griseus*, Gray squirrel.

E. sp. Rubino & Fuentes, 1926.
>> In *Homo sapiens*, Man.

E. sp. Sheather, 1923.   (R) 21-25 x 12-16.
>> In *Sciurus* sp., Squirrel.

E. sp. Visentini, 1914.
>> In *Talpa europaea*, Mole.

E. spherica (A. Schneider, 1887)—[According to Phisalix (1933)].
>> In *Molge cristata, M. palmata, M. punctata*, Newts.

E. spinosa Henry, 1931.   (R) 16.0-22.4 x 12.8-16.0.
>> In *Sus scrofa*, Pig.

E. stankovitchi Pinto, 1928 (c).
>> In *Alburnus brama, A. lucidus,* and *Scardinius erythrophtalmus,* Fish.

E. stiedae (Lindemann, 1865).   (M) 36.9 x 19.9 (Kessel & Jankiewicz, 1931).
>> In *Lepus cuniculus*, Domestic rabbit; and *L. californicus*, Jack rabbit.

E. subepithelialis Moroff & Fiebiger, 1905.   (R) 18-21.
>> In *Cyprinus carpio*, Carp.

E. suis (Nöller, 1921).   (R) 12-33 x 10-20.
>> In *Sus scrofa*, Pig.

E. tenella (Railliet & Lucet, 1891).   (R) 19.6-26.1 x 16.3-22.8.   (M) 22.6 x 19.0 (Tyzzer, 1929).
>> In *Gallus domesticus*, Domestic fowl; and *Colinus virginianus virginianus*, Bobwhite.

E. thélohani (Labbé, 1896).   (R) 25-30.
>> In *Labrus* sp.?, Wrasse.

*E. travassosi** Da Cuhna & Muniz, 1927.
>> In *Dasypus sexcinctus* and *Muletia hybrida*, Armadillos.

E. tritonis (Labbé, 1894) (a).
>> In *Molge cristata*, Newt.

E. tropidonoti Guyénot, Naville & Ponse, 1922.   (R) 22-24 x 12-14.
>> In *Tropidonotus natrix*, Snake.

E. truncata (Railliet & Lucet, 1891).   (R) 20-22 x 13-16.
>> In *Anser anser*, Domestic goose.

E. truttae (Léger & Hesse, 1919).   (R) 10-12.
>> In *Salmo fario*, Salmon.

E. tyzzeri Yakimoff & Rastegaïeff, 1931.   (R) 25.2-37.8 x 18.2-26.6.   (M) 31.76 x 23.25.
>> In *Gallus domesticus*, Domestic fowl.

E. urnula Hoare, 1933.   (R) 17.6-23.2 x 12.8-13.6.
>> In *Phalacrocorax carbo lugubris*, Cormorant.

E. utinensis Selan & Vittorio, 1924.
>> In *Equus caballus*, Horse.

E. variabilis (Thélohan, 1894).   (R) 15-20.
>> In *Anguilla vulgaris, Cottus bubalis, Crenilabrus melops, Gobius bicolor,* and *Lepadogaster gouani*, Fish.

E. viridis (Labbé, 1893) (c).
> In *Rhinolophus fer-equinum,* Bat.

E. volgensis Sassuchin & Rauschenbach, 1932. (R) 23.2-31.9 x 17.4-27.6. (M) 27.2 x 21.9.
> In *Citellus pygmaeus,* Ground squirrel.

E. vulpis Galli-Valerio, 1929. (M) 17 x 14.
> In *Vulpes vulpes,* Fox.

E. wassilewskyi Rastegaïeff, 1930. (M) 18.0 x 14.4.
> In *Cervus axis,* Spotted deer.

E. wenyoni Dobell, 1919. (M) 20.
> In *Homo sapiens,* Man.

E. wierzejski Hofer, 1904. (R) 11-12 (Yakimoff, 1929 a).
> In *Cyprinus carpio,* Carp.

E. yakimovi Rastegaïeff, 1930. (R) 32.4-41.4 x 21.6-28.8.
> In *Boselaphus tragocamelus,* Antelope.

E. zamensis Phisalix, 1921. (R) 28-30 x 15-18.
> In *Zamensis* sp.?, Snake.

E. zurnabadensis Yakimoff, 1931 (b). (R) 25.2-43.2 x 18.0-32.4. (M) 34.1 x 25.0.
> In *Bibos indicus,* Zebu.

E. zürnii (Rivolta, 1878). (R) 15.3-19.1 x 15.3-19.1. (M) 17.1 x 17.1. (Yakimoff & Galouzo, 1927).
> In *Bos taurus* and other Oxen; and *Cervus canadensis,* Wapiti.

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* Genus (?).
‡ Homonym
¶ *Nomen nudum* (see Wenyon, 1926, p. 819).
† Removed to genus Blastocystis (see Wenyon, 1926).
†† Removed to genus Barrouxia (see Wenyon, 1926).
£ Removed to genus Legerella (see Wenyon, 1926).
§ Found in skin; probably not Eimeria.

HOST-INDEX FOR THE GENUS EIMERIA

HOST	SPECIES OF EIMERIA
Phylum—Annelida	
Perichaeta armata	*perichaetae* (Beddard, 1888)
Perichaeta novae-zelandiae	*perichaetae* (Beddard, 1888)
Phylum—Arthropoda	
Class—Myriapoda	
Geophilus ferruginosus—Centipede	*pfeifferi* Labbé, 1896
Glomeris sp?—Millipede	*nova* Schneider, 1881
Himantarium gabrielis	*simondi* (Léger, 1898)
Lithobius forficatus—Centipede	*lacazei* (Labbé, 1895)
	schaudinniana Pinto, 1928
	schneideri Bütschli, 1882
	schubergi Schaudinn, 1900
Stigmatogaster gracilis	*hagenmülleri* Léger, 1898
Tachypodoiulus niger—Millipede	*ekdysios* Triffitt, 1928
Class—Insecta	
Coleoptera Genus?—Beetle	*hyalina* (Léger, 1898)
Gyrinus natator—Whirligig beetle	*hirsuta* Schneider, 1887

Nepa cinerea—Water scorpion   *nepae* Schneider, 1887
Phylum—Chordata
  Sub-phylum Enteropneusta
    Glossobalanus minutus   *beauchampi* Léger & Duboscq, 1917
                                              epidermica Léger & Duboscq, 1917

Sub-phylum Vertebrata
  Class—Elasmobranchii
    Acanthias vulgaris—Spiny dog-fish   *lucida* (Labbé, 1893)
    Aëtobatis narinari—Nari-nari   *southwelli* Halawani, 1929
    Lamna cornubica—Shark   *gigantea* Labbé, 1894
    Mustellus vulgaris—Shark   *lucida* (Labbé, 1893)
    Scyllium sp?—Dog-fish   *scyllii* (Drago, 1902)
    Scyllium catulus—Dog-fish   *lucida* (Labbé, 1893)

  Class—Pisces
    Alburnus brama—Bream   *legeri* (Stankovitch, 1920)
                                              stankovitchi Pinto, 1928
    Alburnus lucidus—Small bleak   *cylindrospora* Stankovitch, 1921
                                              legeri (Stankovitch, 1920)
                                              stankovitchi Pinto, 1928
    Ammodytes tobianus—Sand eel   *bigemina* (Labbé, 1896)
    Anguilla vulgaris—Eel   *anguillae* Léger & Hollande, 1922
                                              variabilis (Thélohan, 1894)
    Barbus fluviatilis   *cyprinorum* Stankovitch, 1921
    Caranx trachurus—Horse mackerel   *cruciata* Thélohan, 1892
    Clinus superciliosus—Klip-fish   *clini* Fantham, 1932
    Clupeus harengus—Herring   *clupearum* (Thélohan, 1894)
    Clupeus pilchardus—Sardine   *clupearum* (Thélohan, 1894)
                                              sardinae (Thélohan, 1890)
    Cobitis taenia—Spiny loach   *cobitis* Stankovitch, 1923
                                              misgurni Stankovitch, 1923
    Cottus bubalis   *variabilis* (Thélohan, 1894)
    Cottus gobio—Bullhead   *cotti* Gautier, 1921
                                              piraudi Gautier, 1921
    Crenilabrus melops   *variabilis* (Thélohan, 1894)
    Cyprinus carpio—Carp   *carpelli* Léger & Stankovitch, 1921
                                              cyprini Plehn, 1924
                                              subepithelialis Moroff & Fiebiger, 1905
                                              wierzejski Hofer, 1904
    Cyprinus gobio—Whitefish   *alburni* (Stankovitch, 1920)
    Engraulis encrasicholus—Anchovy   *clupearum* (Thélohan, 1894)
    Gadus aeglefinns   *gadi* Fiebiger, 1913
    Gadus morrhua—Stockfish   *gadi* Fiebiger, 1913
    Gadus virens   *gadi* Fiebiger, 1913
    Gasterosteus clupeatus   *gasterostei* (Thélohan, 1890)
    Gobio fluviatilis—Gudgeon   *metchnikovi* (Laveran, 1897)
    Gobius bicolor   *variabilis* (Thélohan, 1894)
    Gobius nudiceps—Dikkop   *gobii* Fantham, 1932
    Labrus sp.?—Wrasse   *thélohani* (Labbé, 1896)
    Lepadogaster gouani   *variabilis* (Thélohan, 1894)
    Leuciscus rutilus—Common roach   *alburni* (Stankovitch, 1920)
                                              cyprinorum Stankovitch, 1921
    Misgurnus fossilis—Loach   *misgurni* Stankovitch, 1923
    Motella fusca   *cristalloides* (Thélohan, 1894)
    Motella maculata   *cristalloides* (Thélohan, 1894)
    Motella tricirrata   *cristalloides* (Thélohan, 1894)
                                              motellae (Labbé, 1893)
    Perca fluviatilis—Common perch   *percae* (Dujaric de la Rivière, 1914)
                                              rivierei Yakimoff, 1929
    Phoxinus laevis   *cyprinorum* Stankovitch, 1921
    Salmo fario—Salmon   *truttae* (Léger & Hesse, 1919)
    Scardinius erythrophtalmus—Red roach   *alburni* (Stankovitch, 1920)
                                              cyprinorum Stankovitch, 1921
                                              legeri (Stankovitch, 1920)
                                              pigra Léger & Bory, 1932
                                              stankovitchi Pinto, 1928

Scomber scomber—Mackerel *clupearum* (Thélohan, 1894)
Squalius agassizii *souftae* Stankovitch, 1921
Tinca vulgaris—Tench *cyprini* Plehn, 1924
  minuta Thélohan, 1892
  rouxi Elmassian, 1909

Class—Amphibia
  Hyla arborea—Frog *belawini* Yakimoff, 1929
  Leptodactylus ocellatus—Frog *leptodactyli* Carini, 1931
  Molge cristata—Newt *propria* Schneider, 1881
   tritonis Labbé, 1894
  Molge palmata—Newt *propria* (Schneider, 1881)
  Molge punctata—Newt *propria* (Schneider, 1881)
  Molge taeniata—Newt *propria* (Schneider, 1881)
  Rana sp.?—Frog *pylori* (Gebhardt, 1897)
   ranae Dobell, 1908
  Rana esculenta—Frog *neglecta* Nöller, 1920
   prevoti (Laveran & Mesnil, 1902)
   ranarum (Labbé, 1894)
  Salamandra atra—Salamander *grobbeni* Rudovsky, 1925
   salamandrae atrae (Phisalix, 1927)
  Salamandra maculosa—Salamander *salamandrae* (Steinhaus, 1889)

Class—Reptilia
  Order—Testudinata
   Cistudo europaea—Box tortoise *delagei* (Labbé, 1893)
   Damonia reevesii—Terrapin *mitraria* (Laveran & Mesnil, 1902)
   Emyda granosa—Soft tortoise *legeri* (Simond, 1901)
   Testudo graeca— *brodeni* Cerruti, 1930
  Order Crocodilini
   Crocodilus sp.?—Cayman *pintoi* Carini, 1931
   Gavialis gangeticus—Gavial *kermorganti* (Simond, 1901)
  Order Squamata
   Acanthodactylus scutellatus—
    Fringe-toed lizard *acanthodactyli* (Phisalix, 1930)
   Agama colonorum—Lizard *agamae* (Laveran & Pettit, 1910)
   Anguis fragilis—Blindworm *raillieti* (Léger, 1899)
   Bitis arietans—Puff adder *bitis* Fantham, 1932
   Bothrops neuwiedii—Snake *amarali* Pinto, 1928
   Cerastes cornutus—Snake *cerastis* (Chatton, 1912)
   Cerastes vipera—Snake *cerastis* (Chatton, 1912)
   Coelopeltis lacertina—Snake *coelopeltis* (Galli-Valerio, 1926)
   Coronella austriaca—Snake sp. Grassi, 1888
   Crotalus terrificus—Rattlesnake *crotalae* Phisalix, 1919
   Gekko japonicus—Gecko *gekkonis* Tanabe, 1928
   Hemidactylus mabuia—Gecko *boveroi* Carini & Pinto, 1926
   rocha-limai (Carini & Pinto, 1926)
   Lacerta sp.?—Lizard sp. (Eimer, 1870)
   Python sebae—Python *pythonis* Triffitt, 1925
   Python molurus—Python *pythonis* Triffitt, 1925
   Scincus officinalis—Skink *scinci* (Phisalix, 1923)
   Tamnodynastes strigilis—Snake *arnaldoi* Pinto & Maciel, 1929
   Tropidonotus natrix—Snake *cystis-felleae* Debaisieux, 1914
   tropidonoti Guyénot, Naville & Ponse, 1922
   Tropidonotus natrix var. *persa*—Snake *persica* (Phisalix, 1925)
   Zamensis sp.?—Snake *zamensis* Phisalix, 1921

Class—Aves
  ''Berghühnern'' *caucasica* Yakimoff & Buewitsch, 1932
  Actitis hypoleucos *roscoviensis* (Labbé, 1893)
  Anser anser—Goose *anseris* Kotlán, 1932
   truncata (Railliet & Lucet, 1891)
  Calidris arenaria *roscoviensis* (Labbé, 1893)
  Charadrius cantianus *roscoviensis* (Labbé, 1893)
  Charadrius philippinus *roscoviensis* (Labbé, 1893)
  Colinus virginianus virginianus—

Bobwhite

acervulina Tyzzer, 1929
dispersa Tyzzer, 1929
dispersa (slow-developing variety)
    Tyzzer, 1929
tenella (Railliet & Lucet, 1891)

Columba livia—Domestic pigeon

labbeana Pinto, 1928
pfeifferi (Labbé, 1896)

Fulica atra—Coot
Gallinula chloropus—Moor-hen
Gallus domesticus—Domestic fowl

paludosa (Léger & Hesse, 1922)
paludosa (Léger & Hesse, 1922)
acervulina Tyzzer, 1929
avium (Rivolta, 1878)
beachi Yakimoff & Rastegaïeff, 1931
bracheti Gérard, 1913
globosa (Labbé, 1893)
johnsoni Yakimoff & Rastegaïeff, 1931
maxima Tyzzer, 1929
mitis Tyzzer, 1929
necatrix Johnson, 1930
praecox Johnson, 1930
tenella (Railliet & Lucet, 1891)
tyzzeri Yakimoff & Rastegaïeff, 1931

Lagopus mutus—Ptarmigan
Lyrurus tetrix—Black grouse
Meleagris mexicana—Domesticated
    Turkey

lagopodi Galli-Valerio, 1929
lyruri Galli-Valerio, 1927

meleagridis Tyzzer, 1927
meleagrimitis Tyzzer, 1929

Motacilla alba
Numenius phaeopus
Pelidna torquata
Phalacrocorax carbo lugubris—
    Cormorant
Phalacrocorax cristatus
Phasianus colchious torquatus—
    Ring-necked pheasant

roscoviensis (Labbé, 1893)
roscoviensis (Labbé, 1893)
roscoviensis (Labbé, 1893)

urnula Hoare, 1933
roscoviensis (Labbé, 1893)

dispersa Tyzzer, 1929
phasiani Tyzzer, 1929

Pluvialis apricarius
Strepsilas interpres
Totanus calidris
Tringa alpina

roscoviensis (Labbé, 1893)
roscoviensis (Labbé, 1893)
roscoviensis (Labbé, 1893)
roscoviensis (Labbé, 1893)

Class—Mammalia
  Sub-class—Eutheria
    Division—Didelphia
  Order—Marsupialia
Macropus bennettii—Bennett's wallaby   *macropodis* Wenyon & Scott, 1925
    Division—Monodelphia
      Section—Unguiculata
  Order—Insectivora
Scapanus latimanus—Mole   *scapani* Henry, 1932
Sorex californicus—Shrew   *soricis* Henry, 1932
Sorex vulgaris—Shrew   *soricinae* Galli-Valerio, 1927
Talpa europaea—Mole   sp. Visentini, 1914
  Order—Chiroptera
Rhinolophus fer-equinum—Bat   *viridis* (Labbé, 1893)
Rhinolophus hipposideros—Bat   *hessei* Lavier, 1924
Nyctinomus pumilus—Bat   *dukei* Lavier, 1927
  Order—Carnivora
Canis familiaris—Dog   *canis* Wenyon, 1923
          nuda (Marcone, 1908)
Canis lagopus—Blue fox   *mesnili* Rastegaïeff, 1930
Felis domestica—House cat   *felina* Nieschulz, 1924
          cati Yakimoff, 1933
Felis leo—Lion   *felina* Nieschulz, 1924
Felis tigris—Tiger   *hartmanni* Rastegaïeff, 1930
          novo-wenyoni Rastegaïeff, 1930
Martes zibellina—Sable   *sibirica* Yakimoff & Terwinsky, 1931

Meles taxus—Badger   *melis* Kotlán & Pospesch, 1933
Mephitis hudsonica—Skunk   *mephitidis* Andrews, 1928
Mephitis mephitica—Skunk   *mephitidis* Andrews, 1928
Procyon lotor—Raccoon   *nuttalli* Yakimoff & Matikawschwili, 1932
Putorius putorius var. *furo*—Ferret   *furonis* Hoare, 1927
    ictidea Hoare, 1927
Vulpes vulpes—Fox   *vulpis* Galli-Valerio, 1929
Order—Rodentia
Arctomys marmota—Marmot   *arctomysi* Galli-Valerio, 1931
    marmotae Galli-Valerio, 1923
Arvicola nivalis—Fieldmouse   *arvicolae* (Galli-Valerio, 1905)
Callospermophilus chrysodeirus—
    Golden mantled ground squirrel   *bilamellata* Henry, 1932
    callospermophili Henry, 1932
Cavia aperea—Wild guinea pig   *caviae* Sheather, 1924
Cavia cobaya—Guinea pig   *caviae* Sheather, 1924
Citellus beecheyi—Ground squirrel   *beecheyi* Henry, 1932
Citellus pygmaeus—Ground squirrel   *citelli* Kartchner & Becker, 1930
    volgensis Sassuchin & Rauschenbach, 1932
Citellus tridecemlineatus—
    Ground squirrel   *citelli* Kartchner & Becker, 1930
Cricetus cricetus—Hamster   *falciformis* var. *criceti* Nöller, 1920
Cynomysis ludovicianus—Prairie dog   *cynomysis* Andrews, 1928
Geomys bursarius—Pocket gopher   *geomydis* Skidmore, 1929
Guerlinguetus ingrami—Squirrel   *botelhoi* Carini, 1932
Lepus californicus—Jack rabbit   *magna* Pérard, 1925
    media Kessel, 1929
    perforans (Leuckart, 1879)
    stiedae (Lindemann, 1865)
Lepus cuniculus—Domestic rabbit   *cuniculi* (Rivolta, 1878)
    irresidua Kessel & Jankiewicz, 1931
    magna Pérard, 1925
    media Kessel & Jankiewicz, 1931
    oviformis (Leuckart, 1879)
    perforans (Leuckart, 1879)
    princeps (Labbé, 1894)
    stiedae (Lindemann, 1865)
Lepus timidus—Alpine hare   *leporis* Nieschulz, 1923
Marmota monax—Woodchuck   *monacis*—Fish, 1930
    os Crouch & Becker, 1931
    perforoides Crouch & Becker, 1931
Mus musculus—Mouse   *falciformis* (Eimer, 1870)
    schubergi (Labbé, 1896)
Mus norvegicus—Norway rat   *carinii* Pinto, 1928
    miyairii Ohira, 1912
    nieschulzi Dieben, 1924
    separata Becker & Hall, 1931
Mus rattus—Black rat   *miyairii* Ohira, 1912
    nieschulzi Dieben, 1924
Neosciurus carolinensis—
    Carolina squirrel   *sciurorum* Galli-Valerio, 1922
Neotoma fuscipes—Wood rat   *neotomae* Henry, 1932
    residua Henry, 1932
Ondatra zibethica—Muskrat   *ondatrae-zibethicae* Martin, 1930
Sciurus sp.?—Squirrel   sp. Sheather, 1923
Sciurus griseus griseus—Gray squirrel   sp. Henry, 1932
Sciurus vulgaris—Squirrel   *sciurorum* Galli-Valerio, 1922
Sciurus vulgaris var. *alpina*—Squirrel   *sciurorum* Galli-Valerio, 1922
Order—Edentata
Dasypus sexcinctus—Six-banded
    armadillo   *travassosi* Da Cuhna & Muniz, 1927
Myrmecophaga trigaetyla—Ant-eater   *escomeli* Rastegaïeff, 1930
Muletia hybrida—Armadillo   *travassosi* Da Cuhna & Muniz, 1927
Section—Primates
Order—Primates

Homo sapiens—Man

butkai Causey, 1926
gubleri (Guiart, 1922)
hominis (Rivolta, 1877)
oxyspora Dobell, 1919
snijdersi Dobell, 1920
sp. Rubino & Fuentes, 1926
wenyoni Dobell, 1919

Section—Ungulata
   Order—Artiodactyla
     Bibos indicus—Zebu

bukidnonensis Tubangui, 1931
ellipsoidalis Becker & Frye, 1929
smithi Yakimoff & Galouzo, 1927
zurnabadensis Yakimoff, 1931
zürnii (Rivolta, 1878)

     Bison bison—Bison
     Bos taurus—Ox

smithi Yakimoff & Galouzo, 1927
bukidnonensis Tubangui, 1931
cylindrica Wilson, 1931
ellipsoidalis Becker & Frye, 1929
smithi Yakimoff & Galouzo, 1927
zurnabadensis Yakimoff, 1931
zürnii (Rivolta, 1878)

     Boselaphus tragocamelus—Nylghai
     Capella rupicapra—Chamois
     Capra hircus—Domestic goat

yakimovi Rastegaïeff, 1930
rupicaprae Galli-Valerio, 1923
arloigni (Marotel, 1905)
galouzoi Yakimoff & Rastegaïeff, 1930
ninae kohl-yakimov Yakimoff &
   Rastegaïeff, 1930

     Cervus axis—Spotted deer
     Cervus canadensis—Wapiti

wassilewskyi Rastegaïeff, 1930
hegneri Rastegaïeff, 1930
zürnii (Rivolta, 1878)

     Cervus capreolus—Roe
     Cervus elaphus—Stag

capreoli Galli-Valerio, 1927
cervi Galli-Valerio, 1927
galli-valerioi Rastegaïeff, 1930

     Coelogenus paca—Paka
     Dama dama—Deer
     Gazella subgutturosa—Persian gazelle

nölleri Rastegaïeff, 1930
galli-valerioi Rastegaïeff, 1930
elegans Yakimoff, Gousseff &
   Rastegaïeff, 1932

     Orias canna—Eland
     Ovis aries—Sheep

canna Triffitt, 1924
aemula Yakimoff, 1931
faurei (Moussu & Marotel, 1901)
intricata Spiegl, 1925
ninae kohl-yakimov Yakimoff &
   Rastegaïeff, 1930
parva Kotlán, Mocsy & Vajda, 1929

     Ovis musimon—Sheep
     Sus scrofa—Pig

faurei (Moussu & Marotel, 1901)
brumpti Cauchemez, 1921
debliecki Douwes, 1921
jalina Perroncito, 1901
jalina (Krediet, 1921)
perminuta Henry, 1931
scabra Henry, 1931
spinosa Henry, 1931
suis (Nöller, 1921)

   Order—Perissodactyla
     Equus caballus—Horse

utinensis Selan & Vittorio, 1924

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REPORT ON THE FOOD OF FIVE OF OUR MOST IMPORTANT GAME DUCKS

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Introductory note: During a period of service of about two and one-half years in the Biological Survey, W. F. Kubichek, not only did considerable field work on wild fowl but analyzed all previously unexamined gullet and gizzard contents then on hand of the five leading species of game ducks which at that time were placed in the genus Marila. Since leaving the Biological Survey, Mr. Kubichek has completed the reports on his work which are here given.

The ducks dealt with are the redhead, canvas-back, ringneck, and the greater and lesser scaups. Stragglers of two old-world speceis of this group, the pochard and the tufted duck have been taken on the Pribilof Islands, Alaska, but they are unknwon to most of our hunters, no stomachs have been examined, and they are not reported on here.—W. L. McAtee, in Charge Division of Food Habits Research, U. S. Biological Survey.

REDHEAD
(*Nyroca americana*)

The redhead also known as the American pochard and raft duck, is distributed throughout North America with the exception of Alaska. Its principal breeding range is the central and western parts of the continent, from Michigan, Wisconsin, Iowa, Nebraska, Colorado, Utah, and California, north to British Columbia, Alberta, Great Slave Lake, and Manitoba. It winters in the southern United States, the Bahamas, West Indies, and Mexico. It is a casual visitor to Alaska during migration.

FOOD HABITS

In its habits the redhead resembles its near relative the canvas-back. It is known as a deep water or sea-duck, but is also found inland, on the Atlantic coast feeding in salt or brackish water, in the west inhabiting prairie lakes and sloughs. It is chiefly a vegetarian, for plant food made up 90.85 per cent of all food found in the stomachs examined, while animal matter constituted 9.15 per cent. For the determination of the food habits 358 stomachs were available, most of which were taken in the winter and spring months over a period of 35 years. Only a few were taken in the summer months and these were omitted in computing the final average percentage, so that the results given apply almost entirely to winter and spring months. Of the total number of stomachs, 83 came from Okanagan Landing, B. C. Texas contributed 55 stomachs, Bear River, Utah, 49; Wisconsin 31; Currituck Sound, N. C. 25; Barr Lake, Colo, 21; and various other parts of the country together, 45.

Vegetable Food 90.71 per cent

Pondweeds (Naiadaceae) 38.88 per cent

Pondweeds made up an important item of the food of all ducks. Of

the 358 stomachs of redheads examined, 159 contained the true pondweeds (*Potamogeton*), divided among several species of which the sago pondweed (*Potamageton pectinatus*) was best represented, being found in 62 gizzards. Seeds of pondweeds not further identified were found in 92 stomachs. One gizzard collected in August at the mouth of Bear River, Utah, yielded 1,242 pondweed seeds; others taken at the same time yielded 722; 585; and 435 of these seeds, respectively. Tubers of the pondweeds also were fed upon, and both gizzard and gullet were frequently crammed with them.

Widgeon grass (*Ruppia Maritima*) was found in 79 gizzards, and no fewer than 5,120 seeds of this plant were taken from one gizzard and approximately 1,400 from another. In one gizzard 1,950 and in another 1,600 seeds of bushy pondweed (*Naias marina*) were found. Horned pondweed (*Zannichellia palustris*) was present in only four stomachs, one of which contained 737 fruits of the plant.

Algae 15.92 per cent

Muskgrass (*Chara* sp.) was the most abundant of this group. It was present in almost all the stomachs from Okanagan Landing, B. C., averaging 90.63 per cent for all birds collected there and raising the average for all stomachs containing it to 13.65 per cent. All of the stomachs from this locality were collected in the winter months, and, due to the scarcity of other foods at this time, many of the birds resorted to a strict diet of musk grass. One stomach from Currituck Sound, N. C. contained at least 71,000 oögonia of this plant, another 5,400, and a third 3,200; these were doubtless taken with the plant, and being tougher, persisted in the stomach even after every other trace of the plant had disappeared. Other algae comprised but 2.27 per cent of the total food.

Sedges (Cyperaceae) 9.84 per cent

Seeds of the sedges (Cyperaceae) were found in 86 gizzards of the redhead; apparently other parts of the plants are rarely taken. Fourteen species of sedges contributed to the food of this bird. Among the important ones were three-square (*Scirpus americanus*) which was identified in 18 stomachs, and the river bulrush (*Scirpus fluviatilis*) in 9. Unidentified bulrush seeds were found in 43 gizzards. The following large numbers of seeds were taken from individual stomachs, three-square, 1,660, 1,550, and 435; prairie bulrush (*Scirpus paludosus*), 1,120, 935,570, and 403; spike rush (*Eleocharis* sp.), 1,500 and 670; and sedge (*Carex* sp.), 2,775 and 720.

Grasses (Gramineae) 7.56 per cent

Grasses as a whole were not taken in any quantity and of those eaten the best represented was wild rice (*Zizania aquatica*) which was found in 12 gizzards, amounting to 2.52 per cent of the total. Other grasses identified in the food were switch grass (*Panicum* sp.), wild millet (*Echinochloa crus-galli*), cut-grass (*Homalocenchrus* sp.), salt grass (*Distichlis spicata*) and cultivated oats (*Avena sativa*). Of the latter only a few seeds were found in a single stomach.

Miscellaneous vegetation 18.51 per cent

Wild celery (*Vallisneria spiralis*—2.36 per cent) was found in 17 stomachs, winter buds and tender leaves being the preferred parts. From the findings of this investigation it may be seen that the redhead does not

depend upon wild celery so much as is generally supposed, since only 17 out of 358 gizzards contain it.

The seeds of the water lillies (*Nymphaeaceae*—2.2 per cent) were most abundant in the gizzards of the birds taken in the south during winter. The seeds and rootstocks of the banana waterlily (*Nymphaea mexicana*) made up 11.09 per cent of the food of the 55 birds collected in Texas. Seeds of the sweet-scented waterlily (*Castalia odorata*) were found in 3 gizzards.

Seeds and a few bits of the plants of water milfoil (*Myriophyllum* sp. —1.99 per cent) were found in 13 of the examined stomachs. Three of the stomachs contained seeds of bottle brush (*Hippuris vulgaris*), and the seeds of mermaid weed (*Proserpinaca* sp.) were present in one.

Only 7 of the stomachs contained duckweeds (*Lemna* sp.—1.58 per cent). Redheads prefer large bodies of water and usually feed away from shore and therefore do not get these plants which are so restricted to calm waters.

Coontail (*Ceratophyllum demersum*) was found in 22 gizzards; the birds fed upon both seeds and plants to the extent of 1.46 per cent.

The seeds of 8 species of smartweeds (*Polygonaceae*—1.33 per cent) were taken from the stomachs of the redheads, the most abundant being those of water pepper (*Polygonum hydropiperoides*) which were found in 9 stomachs. Approximately 700 seeds of the dock-leaved smartweed (*Polygonum lapathifolium*) made up a part of the food of one redhead; and 300 seeds of lady's thumb (*Polygonum persicaria*) a portion of the food of another.

At least 5,000 seeds of pigweed (*Amaranthus* sp.) were found in the single stomach containing this plant.

Animal Food 9.16 per cent
Mollusks (Mollusca) 6.52 per cent

By far the greater part of the molluscan food was found in the gizzards of the birds collected in Texas, where they fed upon small snails (*Columbellidae* and *Cerithiidae*). At least 2,400 shells of a small fresh-water snail (*Planorbis parvus*) were present in one stomach. Twenty-six species of mollusk shells were identified from the 358 stomachs.

Miscellaneous Animal Food 2.64 per cent

Insects made up only 2.53 per cent of the food of the redhead, but it should be remembered that the majority of the stomachs were taken during winter, the time when insects are least available. The few gizzards that were taken during early fall months contained a relatively higher percentage of insects, but owing to the very small number of stomachs taken at this time they were not included in the computation of food items. Beetles were most frequently found and were divided chiefly among the diving beetles (*Dytiscidae*), water-scavenger beetles (*Hydrophilidae*) and scarabaeid beetles (*Scarabæidæ*). A few stomachs contained flies (*Diptera*) but the insects of this order found were generally in the larval stage. Approximately 750 larvae of midges (*Chironomidae*) were eaten by one duck. A few of these birds took ants (*Hymenoptera*) or the nymphs of dragonflies or damsel flies (*Odonata*).

The remains of fishes in 2 stomachs made up the total average of .034 per cent for this item of food. Four gizzards contained the remains of crustaceans and 2 contained water mites (*Hydrachnidae*), in quantities

not worth mentioning in either case. Worms (*Annulata*) and fresh water
bryozoa (*Molluscoidea*) were present in one gizzard each.

RING-NECKED DUCK
(*Nyroca collaris*)

The ring-necked duck is known by many common or local names,
among which are the following: ringneck, ringbill, bluebill, blackjack,
raftduck, and tufted duck. This is a more southern bird than the scaup
ducks, breeding from southern British Columbia to northern California,
and from northern Alberta to Lake Winnipge, south to North Dakota,
northern Iowa, and Wisconsin. It winters from southern British Columbia,
northern Texas, southern Illinois, New Jersey, south to Porto Rico and
Guatemala. During migration it may be found in Newfoundland and Nova
Scotia. It has been recorded from Bermuda and England.

FOOD HABITS

Six hundred and fifty-seven stomachs were available for the deter-
mination of the food habits of the ring-necked duck. An inconsiderable
few of these were collected during the late spring, summer, and early fall
months. These, and the nearly empty stomachs, were not considered in the
determination of the final percentages. Of the total 657 stomachs, 553 were
worthy of record. Most of these were collected in southern states: Florida
contributed 360 which were collected in the months November to February
inclusive, Louisiana 120, Arkansas, 51 collected in November and December,
and the remaining 22 from various localities.

Vegetable Food 93.23 per cent
Pondweeds (Naiadaceae) 16.12 per cent

Seven species of pondweeds were identified in the stomachs of the ring-
necked ducks. The smaller pondweed (*Potamogeton pusillus*) was found
in nine stomachs; sago pondweed (*P. pectinatus*) in eight, curly pondweed
(*P. perfoliatus*) in two, (one of which contained 1,520 seeds of the plant
and the other 728), leafy pondweed (*P. foliosus*) in one, and unidentified
pondweeds (*Potamogeton* sp.), chiefly ground up seeds, in 155. Widgeon
grass (*Ruppia maritima*) was taken from fifteen of the stomachs, one
gizzard collected in California in February containing 3,450 seeds. Bushy
pondweed (*Naias flexilis*) was found in ten stomachs and horned pondweed
(*Zannichellia palustris*) in two. Thirty-eight out of fifty-one ducks collect-
ed at Menasha, Arkansas, during November and December consumed pond-
weeds to the extent of 48.82 per cent of all their food.

Waterlily family (Nymphaeaceae) 15.32 per cent

In the stomachs of the ringneck the seeds of waterlilies were much more
conspicuous as a food than in any other species of duck whose food habits
have so far been investigated, being present in 359 of the 657 stomachs ex-
amined. The greatest quantities of them were present in the stomachs from
Florida, 170 out of 360 taken during the winter months containing them.

The seeds of sweet-scented waterlily (*Castalia odorata*) were identified
in 182 gizzards. A few of the larger numbers of seeds present in individual
stomachs are as follows: 1,320, 830, 720, 672, and 660.

Seeds of watershield (*Brasenia schreberi*) constituted an especially
important item of food of the birds collected in Florida from November to

February inclusive. Inidvidual stomachs were found to contain 920, 560, and 430 of these hard ovoid seeds. They amounted to 38.35 per cent of the food of the 314 ducks that fed on it in this locality. Seventy-nine of these birds had eaten the seeds of spatterdock (*Nymphaea microphylla*). One duck consumed 184 of them.

This over-representation of Florida tends to give undue importance to some of the duck foods common there.

Arrowhead family (Alismaceae) 11.66 per cent

Seeds of arrowheads were frequently found in the stomachs, but the bulk of this food consisted of tubers or potatoes, most of which was consumed in the southern states during the winter months. The delta potato (*Sagittaria platyphylla*) was the most abundant representative of this family, the tubers of which were found in sixty-four stomachs and averaged 11.61 per cent of the total. Seven large tubers were found in one stomach. Wapato (*S. latifolia*) was eaten by sixteen of these ducks. No less than 1,040 seeds of arrowheads (*Sagittaria* spp.) were contained in one stomach. These were undoubtedly picked from fruitheads. Of the ninety-six ducks collected near Quarantine, Louisiana, seventy-six had consumed tubers of arrowheads amounting to 73.22 per cent of their entire subsistence.

Many ringnecks, like the gadwalls, (*Mabbott,* 1920) when wintering on the Mississippi Delta, Louisiana, have been found to be feeding on only three items of food; these were the seeds of three-square (*Scirpus americanus*), the delta potato (*Sagittaria platyphylla*), and a small green and black snail (*Neritina reclivata*), all of which are very abundant there.

Sedges (Cyperaceae) 11.29 per cent

Seeds of sedges were well represented in stomachs from all parts of the country. They form a considerable item of food of all species of ducks. Knotted spike rush (*Scirpus etuberculatus*) and Canby's bulrush (*Eleocharis interstincta*) represented this family by their seeds almost to the exclusion of all other sedges from Florida. They amounted to 30.15 per cent of the food of 193 of the 360 birds collected at Micanopy, Florida, from November to February inclusive. Canby's bulrush was identified in 236 stomachs and knotted spike rush in 214, both species frequently appearing in the same gizzard.

The seeds of three-square (*Scirpus americanus*) were present in sixty-one gizzards in numbers as high as 2,780, 2,760, 2,460, 2,240, and 2,096. Bulrush seeds (*S. cubensis*) appeared in nineteen and sawgrass (*Cladium jamaicense*) in eighteen stomachs. Many other sedges were present in smaller quantities. Of the ninety-six stomachs collected at Quarantine, Louisiana, forty-seven had consumed sedges to the extent of 41.83 per cent.

Cyperus ferax was identified from only one stomach, which contained 6,460 seeds.

Frogbit family (Hydrocharitaceae) 8.35 per cent

Although wild celery (*Vallisneria spiralis*) is a very important food item of some species of ducks, the ringnecks took proportionately much less than any other duck treated in this paper. The seeds and leaves of this plant were present in only ten of the examined gizzards. Twenty-seven stomachs contained seeds of fogbit (*Limnobium spongia*). Of frogbit seeds as a ringneck food *McAtee* (1915 p. 5) writes, ''Twenty-five stomachs of

the latter species (ringneck) collected in December contained on the average over 35 per cent of these eagerly sought seeds.'' Practically all of the stomachs, in which these two plants were found, were collected in Louisiana.

Coontail (Ceratophyllaceae) 6.9 per cent

Coontail (*Ceratophyllum demersum*) was present in 128 of the stomachs available for examination. Most frequently only the seeds were present, although the tips of the plants were by no means rare. Both seeds and tips were found in thirty-nine of the fifty-one stomachs collected at Menasha, Arkansas, during November and December. In these thirty-nine this item amounted to 17.74 per cent of all their food. Twenty out of the twenty-four birds collected in Louisiana had utilized this plant to the extent of 16 per cent of their entire diet. One duck had eaten no fewer than 200 of these seeds.

Smartweeds (Polygonaceae) 6.18 per cent

Smartweed seeds were eaten quite frequently by the ringnecks; they constituted 41.80 per cent of the food eaten by 114 of the Florida ducks. The most frequently found, as well as the most abundant smartweed seeds, were those of mild water pepper (*Polygonum hydropiperoides*) which were identified in 202 stomachs, most of which came from the Gulf States and many of which were crammed full of this food. Fifteen stomachs contained over one thousand seeds of this species, the highest four being 8,170, 7,820, 5,960, 5,632. Swamp smartweed (*P. emersum*) was found in eleven, water smartweed (*P. acre*) in ten, dense- flowered smartweed (*P. portoricense*) in eight, water smartweed (*P. amphibium*) in seven, and others in smaller numbers.

Miscellaneous Vegetation 17.41 per cent

Duckweeds (*Lemnaceae*—2.71 per cent) were comparatively more abundant in the ringnecks than in any of the other ducks herein considered. Several stomachs from Florida were well filled with this food. The Florida duckweed (*Wolffiella floridana*) was eaten by twenty-five ducks, unidentified duckweeds (*Lemna* spp.) by twenty and the small duckweed (*Lemna minor*) by one.

Concerning the stomachs from Arkansas which contained duckweeds, McAtee (1915 p. 3) says, ''Fifteen ringnecks had consumed on the average 21.7 per cent each, . . .''

The principal grasses (*Gramineae*—2.69 per cent) taken by these ducks are cut-grass (*Zizaniopsis miliacea*), found in five stomachs, wild rice (*Zizania aquatica*) in four, switch grass (*Panicum* sp.) in three, cockspur grass (*Echinochloa* sp.) in three, and others in smaller numbers. A few grains of barley in one stomach, constiuted the only record in this series of cultivated grain eaten by ringnecks.

The seeds of buttonbush (*Cephalanthus occidentalis*—2.69 per cent) were present in thirty-two stomachs, most of which were collected in November and December near Menasha, Arkansas. The only other representative of this family was cleavers (*Galium* sp.) a few seeds of which were present in two gizzards.

Twenty-three of the twenty-four stomachs contained algae (1.84 per cent) were well filled with musk grass (*Chara* sp.). One stomach collected in January at Currituck Sound, North Carolina, contained no fewer than

35,200 oögonia or reproductive bodies of this plant and approximately 10,-300 were present in a stomach from Alabama.

The pine family (*Pinaceae*) was represented in eleven stomachs by the seeds of loblolly pine (*Pinus taeda*) which amounted to .26 per cent of the total. A few cone scales of bald cypress (*Taxodium distichum*) were found in two gizzards. The hard seeds of bur reeds (*Sparganium* spp.) were identified in thirteen stomachs (.193 per cent).

The water milfoil family (*Haloragidaceae*) made up but .038 per cent of the food. The examination of one stomach from Florida revealed 7,760 seeds of water milfoil (*Myriophyllum* sp.), and one from Athabaska Delta contained 335 seeds (*M. spicatum*). Bayberry seeds were found in twenty-two stomachs, grape seeds in twenty, seeds of hawthorn in twelve, water-penny in eleven, dodder in ten, poison ivy in eight, holly in six, and others in smaller quantities. Approximately 10,000 seeds of water hyssop (*Bacopa rotundifolia*) were present in a stomach from Arkansas, the only one found to contain this plant.

Unidentified seeds, most of them badly worn by gravel, were taken from ten stomachs.

Animal Food 6.66 per cent
Mollusks (Mollusca) 5.25 per cent

The bulk of the animal food was drawn from the mollusks, especially the gastropods. Many of the stomachs from Louisiana were well filled with small shellfish. The largest single item of this food eaten by the ringnecks consisted of a small nerite (*Neritina reclivata*) which appeared in sixty-seven gizzards, taken chiefly in Louisiana. It amounted to 1.45 per cent of the food of these ducks. Fifty-nine of the ninety-six gizzards from Quarantine, Louisiana, contained this mollusk, some of them being crammed full of it.

The shells of *Planorbis narvus* were contained in eleven stomachs, *Planorbis trivolvis* in five, *Planorbis* spp. in fourteen, and *Anachis avara* in five. Many other species were eaten in smaller quantities. Shells are often badly worn by gravel and sand in the gizzards and hence can not be identified with any degree of certainty. Of such shells thirty-three were gastropods, two pelecypods, and eleven merely identified as mollusks.

Miscellaneous Animal Food 1.41 per cent

The group of insects (Insecta—1.40 per cent) most frequently found in the stomachs of these ducks were dragon flies and damsel-flies (*Odonata*), practically all of which were in the nymphal stages. Unidentified nymphs of these insects were present in sixty-four gizzards, damsel-flies or their nymphs in forty, and dragon-flies or their nymphs in fourteen. Beetles (*Coleoptera*) of several kinds were eaten by twenty-seven ducks, flies (*Diptera*) and caddis-flies (*Trichoptera*) by seventeen each. Eight stomachs contained insects of the order Hymenoptera, almost all of which were so badly mutilated as to render further identification impossible. Bugs were not well represented with the exception of the water boatman (*Corixidae*) which were identified in nine stomachs. The order Orthoptera, grasshoppers, crickets, etc., was represented in but five stomachs. Those containing the greatest bulk of insects were collected near Menasha, Arkansas. Had a larger number of stomachs been taken during the warmer months, undoubtedly the amount of insect food would have been much greater.

A few shrimps, crabs, ostracods, and amphipods accounted for .009 per cent of the food. Unidentified fish bones present in ten stomachs made up .007 per cent. The following were represented as mere traces: water mites (*Hydrachnidae*) in seven, fresh water bryozoa, (*Pectinatella magnifica*), chiefly the statoblasts, in five, and earthworms (*Lumbricomorpha* sp.) in four.

Of this duck, Audubon (1840) says: "A male which I shot near Louisville, in the beginning of May, exhibited a protuberance of the neck so very remarkable, as to induce me to cut the skin, when I found a frog, the body of which was nearly 2 inches long, and which had almost choked the bird, as it allowed me to go up within a dozen or 15 paces before I took aim." Stomachs examined for this report failed to disclose any evidence of frogs.

CANVAS-BACK

(*Nyroca valisineria*)

The canvas-back, the most famous duck from the standpoint of the epicure, ranges throughout North America. Its breeding range extends from Central British Columbia, Fort Yukon, Great Slave Lake and southwestern Keewatin south to Oregon, Nevada, Nebraska, and southern Minnesota. It winters from southern British Columbia, Nevada, Colorado, Illinois, Pennsylvania and western New York south to central Mexico and the Gulf coast. In migration it rarely reaches New Brunswick and Nova Scotia. A few wander to Bermuda and the West Indies.

FOOD HABITS

The food habits of the canvas-back were determined from the examination of 381 stomachs. The greater part of this number represents birds taken chiefly in the southern states during the winter and spring months (December to April). The largest series were collected at the following localities: Triumph P. O., La. which contributed 113, Lake Surprise, Texas, 36, Marquette, Wis., 24, Mississippi Delta, 22. Each of these localities furnished a special food and these particular items raised the percentage for that food in the final average. The following will illustrate the above statement: 103 out of 113 canvas-backs from Triumph P. O., La. fed very largely on the tubers of delta duck potato (*Sagittaria platyphylla*) which averaged 66.46 per cent of their food. Ninety-five out of these 113 birds took the small snail (*Neritina reclivata*) to the extent of 19.43 per cent of their diet.

Vegetable Food 84.8 per cent

Waterlilies (Nymphaeaceae) 19.49 per cent

Seeds of the waterlilies were taken by 57 of the canvas-backs; the gizzards from Lake Surprise, Texas, containing seeds and rootstocks of the banana waterlily (*Nymphaea mexicana*) raised the representation of this family to 19.49 per cent of the total food. Thirty-four of thirty-six birds fed on this plant to the extent of 76.36 per cent. Nineteen had eaten the seeds of the sweet-scented waterlily (*Castalia odorata*), and 3 those of water shield (*Brasenia schreberi*).

Pondweeds (Naiadaceae) 17.85 per cent

Although all parts of pondweeds were eaten, the seeds made up the greater part of the food derived from this family. All ducks seem to be

especially fond of the hard seeds of these plants. Pondweeds were represented in 228 of the 381 stomachs examined, the true pondweed (*Potamogeton* spp.) being found in 189 gizzards. The numbers of tubers of the sago pondweed (*Potamogeton pectinatus*) found in the gizzards and crops verifies the statement that this plant makes an excellent food with which to attract these ducks. One gizzard and one crop contained 59 tubers, another 57, some of which measured ½ inch in thickness and ¾ inch in length; a third contained 52 tubers. Pondweed seeds were frequently found in large numbers in single stomachs, those of sago pondweed in the following numbers, 2,560, 504, and 221. Widgeon grass (*Ruppia maritima*) was identified in 22 and bushy pondweed (*Naias flexilis*) in 4 stomachs.

Arrowheads (Alismaceae) 15.7 per cent

The delta duck potato (*Sagittari palatyphylla*) was the most frequently identified species, being found in 119 gizzards and averaging 15.46 per cent of the contents of the total number of stomachs. One hundred and three out of 113 gizzards from Triumph, P. O., La., contained this plant and it averaged 66.46 per cent for the ducks from that place. Other parts of the Mississippi Delta furnished 22 gizzards, 16 of which contained the same plant to an average extent of 43.86 per cent. The following large numbers of tubers were found in the gizzards and crops of individual ducks: 36, 20, 13, 12, and 11.

Grasses (Gramineae) 11.49 per cent

Though an excellent duck food the seeds of wild rice (*Zizania aquatica*) were found in only 26 of our canvas-back stomachs. Twenty out of twenty-four stomachs collected in April near Marquette, Wisconsin, contained wild rice, to the extent of 57.54 per cent of their subsistence. One had consumed 128 seeds and another 116.

Among other grasses represented in the food by their seeds were: wild millet (*Echinochloa crus-galli*), and cut-grass (*Leersia* sp.).

Frogbit family (Hydrocharitaceae) 10.8 per cent

Wild celery (*Vallisneria spiralis*) was the only member of this family taken by these ducks, being present in 40 stomachs; no wild celery was found in the stomachs from the south. Some leaves of the plant were eaten but the rootstocks and winter buds were the preferred parts. The canvasback has been reputed to feed largely upon wild celery but from the results obtained in the present investigation it is evident that the bird is no more fond of this plant than of certain others. However, the results might have been modified had a larger number of the stomachs examined been collected in places where this plant grows in abundance.

Miscellaneous vegetation 9.47 per cent

Usually only the seeds of sedges (*Cyperaceae*—2.94 per cent) are taken but tender parts of these plants also were found in the stomachs. Eleven species of sedges were eaten by the canvas-backs examined. Seeds of bulrushes (*Scirpus* sp.) were found in the largest number of stomachs, the species best represented being three- square (*Scirpus americanus*) which was found in 128 gizzards, river bulrush (*Scirpus fluviatilis*) in 18, salt-marsh bulrush (*Scirpus robustus*) in 12, and prairie bulrush (*Scirpus paludosus*) in 10. Unidentified bulrushes were found in 61 stomachs.

The following series indicate the larger numbers of seeds of three-square found in individual gizzards of the canvas-back, 2,390, 2,280, 1,550, 1,256, 900, 880, 860, and 752.

Musk grasses (*Chara* spp.) were the best represented among the algae; they were found in 13 stomachs and averaged 0.70 per cent of the total food. At least 1,600 oögonia of this plant were found in the gizzard of one canvas-back taken in Louisiana in November. Unidentified algae were present in 5 stomachs.

Water milfoil (*Myriophyllum* spp.) was present in 24 of the stomachs examined, constituting an average of 0.97 per cent. Seeds were most abundant but parts of the foliage also were found. In a few cases large numbers of seeds were present in individual gizzards as illustrated by the following numbers, 1,224, 1,045, and 557. Seeds of bottle brush (*Hippuris vulgaris*) were found in 4 stomachs and those of mermaid weed (*Proserpinaca palustris*) in one.

The seeds were the only parts of the smartweeds (*Polygonaceae*—0.71 per cent) eaten by the canvas-back ducks. Eight species of these plants were identified in the stomach contents. The most common form was water-pepper (*Polygonum hydropiper*) which was found in 21 of the stomachs, one containing 380 seeds of this plant. *Polygonum lapathifolium* was second, being found in 9. The seeds of dock (*Rumex* spp.) were present in only two of the stomachs.

Coontail (*Ceratophyllum demersum*—0.62 per cent) was found in 33 gizzards, the seeds and the foliage of the plant being taken in about equal proportion.

The seeds of bur-reed (*Sparganium* spp.—0.28 per cent) were found in 17 stomachs of the canvas-back, but no trace of other parts of the plant was found. The seeds of *Sparganium eurycarpum* were taken by 7 of these ducks; *Sparganium multipedunculatum* by 4, one of which contained 283 seeds; *Sparganium americanum* by 2; and unidentified bur-reeds (*Sparganium* sp.) by 4.

Duckweeds (*Lemnaceae*—0.12 per cent) were eaten by only 5 of these birds, *Lemna* sp. by 3, big duckweed (*Spirodela* sp.) by 2. At least 1,600 nearly entire plants of the big duckweed and the ground up remains of many more were found in the gizzard of one canvas-back taken in Louisiana in February.

The remainder of the vegetable food was made up of many small items among which the following were most common, appearing in the number of stomachs indicated by the number following the name: cleavers (*Galium* sp.) 4, bayberry (*Myrica* sp.) 3, bald cypress (*Taxodium distichum*) 2, pigweed (*Chenopodium* sp.) 2, dogwood (*Cornus* sp.) 2, bogbean (*Menyanthes trifoliata*) 2, and Spanish needles (*Bidens* sp.) 2.

Animal Food 15.15 per cent

Mollusks (Mollusca) 12.55 per cent

By far the greater part of the animal food consisted of small snails (*Neritina reclivata*) which were found in 104 gizzards collected at Triumph P. O., La. and made up 19.43 per cent of the food of these birds. Unidentified gastropods were eaten by 34 birds, and other snails taken were as follows,—*Nassa acuta* by 4, *Anachis obesa* by 3, and *Tornatina canaliculata* by 2. Unidentified bivalves were taken from 14 of the stomachs and *Macoma nasuta* from 12.

Miscellaneous Animal Food 2.60 per cent

Since most of the available stomachs were collected in the winter and early spring months,—a time when few insects are active,—insects constituted only 1.45 per cent of the total food. Had a series of gizzards from the breeding range been examined insects no doubt would have been much better represented. The few stomachs representing the late spring and early summer months showed a much higher percentage of insects but were omitted from the final computation on account of the small amount of food they contain. Beetles (*Coleoptera*) in both the larval and adult stages were present in 27 of the stomachs. Flies and their larvae (*Diptera*) were second in importance, being found in 26 of the gizzards, the larval stages by far the most abundant. The larvae of the midges (*Chironomidae*) were present in 18 of the stomachs; one of these contained the remains of at least 130 of these larvae and another no fewer than 112. Bugs (*Heteroptera*) were found in 12 gizzards, Mayflies (*Ephemeroptera*) and their nymps were taken by 8 birds, damsel-flies (*Zygoptera*) and their nymphs by 7, and dragon-fly nymphs (*Anisoptera*) by 1. Remains of dobson fly (*Corydalis cornuta*) larvae were present in 4 gizzards, caterpillars (*Lepidoptera*) in 4, the larvae and larval cases of caddis-flies (*Trichoptera*) in 3, and a spider (*Arachnida*) in 1.

The remains of fishes, chiefly scales and bones, were found in 27 gizzards. A tooth of a rat (*Muridae*) and the vertebrae and teeth of muskrats (*Ondatra rivalicia*) were probably picked up with gravel by the 9 birds which had swallowed them. Crustaceans were eaten by only 2 birds.

GREATER SCAUP DUCK
(*Nyroca marila*)

The scaup duck is a rather common bird known by many local names, among which are blue bill, broadbill, blackhead and grayback. It breeds from the northern United States northward to Alaska and the Aleutian Islands. In the fall it migrates to the southeast and reaches the Atlantic coast, the Bahamas, the Gulf Coast and southern California. It is rare in migration in Newfoundland and Nova Scotia.

FOOD HABITS

The stomachs of 710 scaup ducks were available for this investigation. They were collected over the greater part of North America but the western part is best represented, as Oyster Bay, Wash., furnished 310, Okanagan Landing, B. C., 67, and Bear River, Utah, 50. Six hundred and forty-four of the examined stomachs were used in computing the percentages as given in this report, the remainder being nearly empty or widely scattered through the summer months. Most of them were collected in the months from October to April inclusive.

Vegetable Food 67.14 per cent
Pondweeds (Naiadaceae) 26.37 per cent

Of the true pondweeds (*Potamogeton* spp.), the seeds of the sago pondweed (*Potamogeton pectinatus*) were most frequently found. They appeared in 37 of the stomachs examined. The seeds of five other species of pondweeds (*Potamogeton* spp.) were found in one stomach each. The seeds of widgeon grass (*Ruppia maritima*) were eaten by 134 of these ducks and

the following numbers of seeds were taken from individual stomachs: 1,350, 1,000, 988, and 500. Fifty-one of the gizzards contained the seeds of the bushy pondweed (*Naias flexilis*), nineteen the seeds and parts of the plant of the horned pondweed (*Zannichellia palustris*), and seven the seeds of eel grass (*Zostera marina*.) No less than 1,600 seeds of the pondweeds (*Potamogeton* spp.) were found in one stomach and 400 in another. Forty-nine out of fifty stomachs collected at the mouth of the Bear River in Utah during October and November contained the seeds of Pondweeds (*Potamogeton* spp.) and widgeon grass (*Ruppia maritima*), making an average of 58.75 per cent of all food eaten there.

Algae 20.71 per cent

The total percentage for algae was raised by the 67 gizzards collected at Okanagan Landing, B. C., where Chara was the common food of this species of duck. These stomachs were taken from November to February inclusive and 52 out of 67 contained this plant; a few were crammed with it. The ovid oögonia were not picked up individually but were eaten with the plant and, being resistant, remained in the gizzard after the other parts had been digested. One stomach, collected in Currituck Sound in February, contained no less than 83,000 whole oögonia and the pieces of at least three times as many more, representing a total of about 332,000. Another gizzard from the same place contained 4,128 oögonia.

Wild Celery (Hydrocharitaceae) 6.95 per cent

Wild celery (*Vallisneria spiralis*) was eaten by 45 of these ducks and was most abundant in the gizzards of those collected in Currituck Sound, N. C. Very few seeds of this plant were found, for the preferred parts were the rootstocks, buds, and some leaves. No great quantity was found in any stomach.

Miscellaneous Vegetation 13.11 per cent

The seeds of the sedges (*Cyperaceae*) were practically the only parts of these plants present and they made up 3.8 per cent of the total. Seeds of unidentified bulrushes were taken from 88 stomachs. Three-square (*Scirpus americanus*) was the most common identified form and was found in 25 of the gizzards. The following were present in the number of stomachs indicated: prairie bulrush (*Scirpus paludosus*) 11, river bulrush (*Scirpus fluviatilis*) 6, salt-marsh bulrush (*Scirpus robustus*) 3, twig rush (*Cladium mariscoides*) 7, saw grass (*Cladium jamaicense*) 5, and spike rush (*Eleocharis* sp.) 3.

The seeds and tubers of the arrow-heads (*Alismaceae*—1.6 per cent) were present in 7 of the gizzards and represent one locality, Okanagan Landing, B. C. A few seeds of water plantain (*Alisma* sp.) were eaten by one of these ducks.

Grasses (*Gramineae*—1.04 per cent) appeared in the contents of 32 of the stomachs available for examination. Wild rice (*Zizania aquatica*) was the most frequently identified species. The seeds of it were taken from 11 of the stomachs and averaged .49 per cent for the total number examined. Five of the birds had eaten the seeds of switch grass (*Panicum* sp.). Eight other grasses were present in one stomach each but none in any quantity worth mentioning.

The seeds of smartweeds (*Polygonaceae*—.95 per cent) were taken from

54 of the gizzards. Water smartweed (*Polygonum amphibium*) was identified in 18 stomachs, lady's thumb (*Polygonum persicaria*) in 5, water pepper (*Polygonum hydropiper* and *Polygonum densiflorum*) in 2 each. At least 300 seeds of lady's thumb were taken from one stomach from Colorado. Five stomachs contained the seeds of golden dock (*Rumex persicarioides*) and eight the seeds of an unidentified dock (*Rumex* sp.).

Bits of the plant as well as the seeds of coontail (*Ceratophyllum demersum*) were present in 35 of the gizzards and represent .83 per cent of the total. The seeds of water milfoil (*Myriophyllum spicatum* and *Myriophyllum* sp.) were eaten by 42 of these ducks. Seven gizzards contained the seeds of bottle brush (*Hippuris vulgaris*). The water milfoils and bottle brush averaged .72 per cent for all the examined stomachs of the scaup ducks.

The seeds of the bur-reeds (*Sparganiaceae*—.24 per cent) were divided as follows: Unidentified in 9, *Sparganium multipedunculatum* in 2, *Sparganium eurycarpum* in 2, and *Sparganium androcladum* in one.

Proportionately fewer seeds of the water lilies (*Nymphaeaceae*—.13 per cent) were eaten by the scaup duck than any other duck treated in this report. Water shield (*Brasenia schreberi*) was eaten by 7, yellow pond lily (*Nymphaea* sp.) by 3, white water lily (*Castalia* sp.) and yonkapin (*Nelumbo lutea*) by one each.

The remaining vegetable food, made up chiefly of the seeds of 30 different plants, constituted 3.8 per cent of the total. Most of the seeds were present in one stomach each, those present in larger quantities were bayberry (*Myrica* sp.) in 16, marsh pennywort (*Centella asiatica*) in 7, buttonbush (*Cephalanthus occidentalis*) in 4, pigweed (*Amaranthus* sp.) and dogwood (*Cornus* sp.) in 3 each; pepperwort (*Marsilea* sp.), clover (*Trifolium* sp.), black crowberry (*Empetrum nigrum*), grape (*Vitis* sp.), Spanish needles (*Bidens bidentoides*) and duck weeds (*Lemna* sp.) in 2 each. One duck collected at Micanopy, Florida, in December, had eaten 7,680 seeds of glasswort (*Salicornia ambigua*).

Animal Food 32.78 per cent

Mollusks (Mollusca) 25.14 per cent

The average for this item of food was raised greatly by the gizzards from Oyster Bay, Wash., where mollusks constituted 84.73 per cent of the food of the scaup duck. This series of stomachs was collected during a special investigation to determine whether or not these ducks were being rightly accused of damaging the oyster beds. The 310 stomachs from there were taken from November to April inclusive. Oysters (*Ostrea lurida*) formed 41.58 per cent of the food of the ducks taken there; 231 out of the 310 contained this item of food and fragments representing 48, 40, 39, 36, 34, 30, 24, 23 and on down were found in individual stomachs. These large numbers very probably represented several meals, for the diagnostic parts are hard and not as readily crushed as the rest of the shell. The largest oysters remaining whole in the stomachs measured as follows: 1⅝″ x 1¼″, 1⅜″ x 1⅛″, 1⅜″ x 1″, 1⁵⁄₁₆″ x 1¹⁄₁₆″. A total of 245 of the stomachs of these ducks contained this mollusk.

The edible mussel (*Mytilus edulis*) and the bent-nosed macoma (*Macoma nasuta*) each formed 2.3 per cent of the total and were contained chiefly in the stomachs from Oyster Bay, Wash. The edible mussel was eaten by 137 of the scaup ducks. One gizzard contained four of these

animals, one of which measured 2″ x ⅞″. Ninety-eight of the stomachs contained the remains of the bent-nosed macoma. The same locality was responsible for the increased percentage (2.2 per cent) of the lean nassa (*Nassa mendica*), which was found in 101 stomachs and of which 152 shells were taken from one gizzard and crop. The ribbed carpet shell (*Paphia staminea*) was eaten by 109 of the ducks collected at Oyster Bay, Wash., and averaged 6.93 per cent for the series from that locality or 1.9 per cent for the total number of scaup ducks. The most important among the remaining 71 species of shells that were found were present in the following numbers: *Thais lamellosus* 34, *Acamae persona* 16, *Crepidula lingulata* (slipper shell) 14, *Nitidella gouldi* 13, *Anachis avara* 12, *Astyris lunata* 11, *Anachis obesa* 9, *Ilyanassa obsoleta* 9, *Nassa trivittata* 9, *Tornatina cerealis* 9, *Bittium nigrum* 8, *Mangilia stellata* 7, *Goniobasis virginica* 5, *Odostomia menestho trifida* 5. Two hundred and eighty-five small dog whelks (*Nassa trivittata*) were found in one stomach and 275 in another, both collected in Main in November. Ninety-two shells of the checkered littorina (*Littorina scutulata*) were taken from the only stomach containing this species. One had eaten 76 small gastropods (*Nitidella gouldi*). A gizzard from North Carolina contained at least one thousand small worn gastropods. One thousand four hundred and ninety small univalves of two species (*Bittium nigrum* and *Triforis adversa*) were taken by a scaup duck which was collected at Goose Creek, Florida.

A small bivalve (*Mulinia lateralis*) was common in the stomachs of the ducks collected at St. Vincent Island, Florida. Sixty-eight entire shells and the pieces of 55 more were taken from one gizzard and crop; other large numbers were 76 and 73.

Miscellaneous Animal Food 7.64 per cent

The insect diet was low, 4.2 per cent, as it was in most of the other species treated in this report, for very nearly all the stomachs available were taken from ducks shot from November to April, a time when comparatively few insects are to be found. Flies and their larvae were present in 51 stomachs; 29 contained midges (*Chironomidae*) or their larvae and 12 the larvae of the Ephydridae. Four hundred and thirty-three midge larvae (*Chironomidae*) were counted in the contents of one stomach and 207 in another, both collected in Missouri in April. A specimen from Kansas, collected in October, had devoured 147 muscoid larvae. Thirty-two had eaten beetles (*Coleoptera*) and 29 the larvae and larval cases of the caddis-flies (*Trichoptera*). Twenty-three contained the remants of true bugs and all but one of this number were water-boatmen (*Corixidae*). Five stomachs contained ants and wasps (Hymenoptera), 2 dragon flies (*Anisoptera*) and 3 mayflies (*Ephemeroptera*).

The Crustaceans produced 1.61 per cent of the food of these ducks and the most frequently found species was a small crab (*Hemigrapsus oregonesis*) which was indentified in 31 of the stomachs from Oyster Bay, Wash. Other species of crabs found were *Lophopanopeus bellus* in 2 gizzards, *Cancer gracilis* in 1, and the hermit crabs, *Pagurus hirsutinsculus* and *Pagurus granosimanus*, in one each. Only one gizzard, collected at Nantucket, contained mud crabs (*Neopanope texana sayi*), one of which measured 1½″ x 1″. Only two contained the remains of crawfishes (*Astacidae*). Amphipods (*Amphipoda*) were found in 13 stomachs, ostracods (*Ostracoda*) in 10, fairy shrimps (*Phyllopoda*) in 6, and isopods (*Isopoda*) in 4.

One hundred and twenty-six out of the 129 gizzards in which barnacles were found were collected at Oyster Bay, Washington, where *Balanus glandula* was taken quite frequently and formed 7.54 per cent of the food of the 310 stomachs from that locality and 1.51 per cent of the total. Another barnacle (*Chthamalus dalli*) was identified in three gizzards; one unidentified barnacle was found in the entire series.

The remaining animal food, which constituted .32 per cent of the total, was made up of many items in small quantities. Statoblasts of the fresh water bryozoa (*Phylactolaemata*) were found in 22 of the gizzards; in 15 of these they were identified as *Cristatella mucedo*. These small parts were very probably picked up with other food. Five contained hydroids (*Hydrozoa*), 9 the bones and scales of fishes (*Pisces*), 5 water mites (*Acarina*) and worms (*Annulata*) were present in three.

LESSER SCAUP DUCK
(*Nyroca affinis*)

The lesser scaup duck resembles its larger relative, the greater scaup duck, very closely and is known by nearly the same common names. The adult male lesser scaup duck is so much like the adult male greater scaup duck that only with difficulty can the two be separated.

The species range extends over the greater part of North America. It breeds from the Yukon and Mackenzie river valleys south to central British Columbia, Montana, northern Iowa, and western Lake Erie. It winters in British Columbia, Nevada, Lake Erie, and New Jersey south to the Bahamas and Panama. It is rarely found in Newfoundland, New Brunswick, and Nova Scotia, and is accidental in Bermuda and Greenland.

FOOD HABITS

A total of 1,021 stomachs, many accompanied by well filled gullets, were available for the determination of the food habits of this species. Due to difficulty in distinguishing the scaup ducks, it is likely that there is more or less mixtures of the stomachs. The results here cited were obtained from 922 which were used in computing averages. A rather large proportion (525) of the total number of birds was taken at Marquette, Wisconsin, most of which had been reported killed by lead poisoning. Nearly all of these stomachs contained shot, the largest number in one gizzard being fifty-seven. Although a few of the gizzards and gullets were empty, most of them were crammed full of food. The over-representation of the Marquette region tends to give undue importance to the duck feed common in this locality. This is especially noticeable in regard to wild rice (*Zizania aquatica*). Currituck Sound, North Carolina, furnished 114 gizzards; Florida, eighty-six; Klamath Falls, Oregon, forty-eight; Alabama, twenty-two; Louisiana, thirteen; miscellaneous localities, 114.

Vegetable Food 59.96 per cent
Pondweeds (Naiadaceae) 23.79 per cent

Considerable quantities of this important duck food plant were eaten by the ducks from all localities. Seeds made up the bulk of this food, although the foliage and tubers also were eaten. Six species of pondweeds were identified in this lot of stomachs. Ground down seeds of pondweeds (*Potamogeton* spp.) not further identified were found in 728 gizzards. The most important of these plants from the standpoint of duck food is the sago

pondweed (*Potamogeton pectinatus*) which was identified in ninety-four
of the stomachs. The floating pondweed (*Potamogeton natans*) was taken
from eighteen stomachs, while other species were found in smaller numbers.
Widgeon grass (*Ruppia maritima*), another member of this family, was
identified in 224 stomachs and as many as 3,280 seeds in one. "Nineteen
little bluebills collected in January (St. Vincent Island, Florida) had
eaten it, principally the seeds, to the extent of over sixty-three per cent of
their food". (McAtee, 1915, p. 16). The foliage and seeds of the bushy
pondweed (*Naias flexilis*) were eaten by 314 of the ducks. One gizzard
from Wisconsin contained 2,416 of these seeds. The horned pondweed
(*Zannichellia palustris*) was identified in eleven gizzards, one of which
contained no less than 2,500 fruits of this plant.

Grasses (Gramineae) 10.43 per cent

Grasses made up about one-tenth of the food of the lesser scaup duck.
This was found in greater proportions in the stomachs taken in Wisconsin,
where wild rice (*Zizania aquatica*) was an important item of food. With
the exception of .007 per cent, all the wild rice kernels were found in 504
of the 525 stomachs examined from that locality, making 66.23 per cent of
their food. Wild millet (*Echinochloa crus-galli*) was identified in thirty
stomachs, switch grass (*Panicum* sp.) in ten, rice cut grass (*Homalocenchrus
oryzoides*) in nine, cockspur grass (*Echinochloa* sp.) in eight, and foxtail
(*Chaetochloa* sp.) in seven.

Algae 5 per cent

Algae were found in 121 stomachs of which number 118 contained
musk grass (*Chara* sp.). This plant constituted 29.74 per cent of the food
eaten by the 114 birds taken at Currituck Sound, North Carolina. "Three-
fifths of the food of seventy little and thirty-five big bluebills taken in that
locality in November, 1909, consisted of musk grass." (McAtee, 1915 p. 1).
Oögonia, the reproductory bodies of these plants, appeared in abundance
in these stomachs. One contained approximately 20,600 of them.

Miscellaneous Vegetable Food 20.74 per cent

Many of the sedges (*Cyperaceae*—3.69 per cent) contributed to the food
of the lesser scaup duck; the seeds or entire fruitheads, however being almost
the only part of the plant consumed. Bulrushes (*Scirpus* sp.), not further
identified, were found in 376 of the stomachs examined, the river bulrush
(*S. fluviatilis*), found in 317 stomachs, making up the greatest bulk from
this source. Three-square (*S. americanus*) was second in the list, being rep-
resented in 250. Other bulrushes were taken in smaller quantities. Seeds
of sedges (*Carex* sp.), not further identified because of their worn down
condition, were found in 163 stomachs. Saw grass (*Cladium jamaicense*)
was fed upon by sixty of the ducks. Twig rush (*Cladium mariscoides*) was
taken from fifteen, chufa (*Cyperus* sp.) from thirty-one, and spike-rush
(*Eleocharis* sp.) from sixteen.

Seeds, plants, and winter buds of wild celery (*Vallisneria spiralis*—
3.45 per cent) were found in the stomachs of 174 ducks, most of this num-
ber having been taken at Currituck Sound, North Carolina. Waterweed
(*Philotria canadensis*) another member of this family, was identified in
only nineteen.

Smartweeds (*Polygonaceae*—2.93 per cent) grow abundantly in moist

or wet areas and make up one of the favorite food items of wild ducks. While the seeds of these plants are the only parts edible, they are highly nutritious in food value. Eleven species of smartweed seeds were found in the stomachs of the lesser scaup ducks examined. The species of most frequent occurrence was water pepper (*Polygonum hydropiper*) which appeared in 155 of the stomachs. Next in importance was the dockleaved smartweed (*P. lapathifolium*), the seeds of which were present in sixtynine. Others identified were arrow-leaved smartweed (*P. sagittatum*) and mild water pepper (*P. hydropiperoides*) found in sixteen each, one of which contained 9,840 seeds of the latter plant. Water smartweed (*P. amphibium*) was identified in nine, and other species in smaller numbers. Smartweed seeds not further identified were found in thirty stomachs.

The seeds of waterlilies (*Nymphaeaceae*) averaged two per cent of the food. The stomachs of thirty-five lesser scaup ducks contained the seeds of water shield (*Brasenia schreberi*); eighteen were found to have eaten seeds of the sweet-scented water lily (*Castalia odorata*), and thirteen the seeds of spatterdock (*Nymphaea advena*). Seeds of the banana water lily (*N. mexicana*) were common items of food taken by the ducks collected in Florida. Six of them had partaken freely of this plant, one of which had eaten no less than 200 seeds.

The water milfoil family (*Haloragidaceae*—.77 per cent) made up a large item of food of the ducks collected in Alabama, although it was found to be a rare source of food in other localities. Seeds and foliage of water milfoil (*Myriophyllum spicatum*) were taken from 115 stomachs and bottle brush (*Hippuris vulgaris*) from fourteen. Seeds of water milfoil (*Myriophyllum* spp.) not further identified also occurred in fourteen.

While eaten by the five species of diving ducks treated in this paper, coontail (*Ceratophyllum demersum*—.63 per cent) was more frequently found in the stomachs of the lesser scaup duck than in any of the others. Both seeds and foliage were found in 247 stomachs of this species.

Wapato or duck potato (*Sagittaria latifolia*) is a member of the family known as arrow-heads (*Alismaceae*—.49 per cent) all of which have large nutritious tubers. Five stomachs contained tubers and a few seeds of this plant. Arrow-heads (*Sagittaria* spp.), not further identified, were found in seven; while the tubers and seeds of water plantain (*Alisma plantago aquatica* and *Alisma* sp.) were found in ten stomachs.

Bur reeds (*Sparganiaceae*) constituted .17 per cent of the food of the lesser scaup duck. Among the bur reeds were found *Sparganium eurycarpum*, identified in twenty-five stomachs, *S. multipedunculatum* in fifteen, and *S. americanum* in six. Next in importance were duckweeds (*Lemnaceae*) which came in for an average of .08 per cent. Fourteen stomachs contained water meal (*Wolffia punctata* and *Wolffia* sp.) and five contained duck weed (*Lemna* sp.). Other plants that deserve mention are cleavers (*Galium* sp.), the seeds of which were found in forty-four stomachs; the seeds of bayberry (*Myrica cerifera*) in three, and *Myrica* sp. in thirty. Seeds of buttonbush (*Cephalanthus occidentalis*), a crooked, stiff-branched shrub, were taken from five stomachs. Other seeds included in the list were those from dodder (*Cuscuta* sp.), which occurred in eleven, pigweed (*Chenopodium* sp.) and grape (*Vitis* sp.) in eight each. Seeds of composites not further identified were found in seventeen stomachs.

W. F. KUBICHEK

TABULAR SUMMARY OF FOOD HABITS DATA

Species	No. of stomachs examined	VEGETABLE FOOD										ANIMAL FOOD			
		Total percentage	Wild celery and allies	Pond weeds	Grasses including wild rice	Musk grasses and other algae	Wapatos	Sedges	Water lilies	Coon tail	Misc. vegetable Food	Total percentage	Mollusks	Insects	Misc. animal Food
Redhead	358	90.71	2.36	38.88	7.56	15.92	trace	9.84	2.2	1.46	12.49	9.16	6.52	2.53	.11
Ringneck	657	93.23	8.35	16.12	2.69	1.84	11.66	11.29	15.32	6.9	19.06	6.66	5.25	1.40	.01
Canvas-back	381	84.8	10.8	17.85	11.49	1.22	15.7	2.94	19.49	0.62	4.69	15.15	12.55	1.45	1.15
Greater scaup	710	67.14	6.95	26.37	1.04	20.71	1.6	3.8	0.13	0.83	5.71	32.78	25.14	4.2	3.44
Lesser scaup	1021	59.96	3.68	23.79	10.43	5.00	0.49	3.69	2.00	0.63	10.25	39.93	34.18	3.79	2.01

Animal Food 39.93 per cent
Mollusks (Mollusca) 34.13 per cent

The mollusks were an important item of food of the lesser scuap duck, for frequently the stomachs examined contained but little other food. The number of species of mollusks was proportionately greater in this duck than in any other treated in this paper. Sixty-nine species of mollusks belonging to sixty-five genera were identified in these stomachs. This type of food was commonly found in the stomachs from Klamath Falls, Oregon, and Louisiana. Unidentified ground up shells were present in seventy-four and unidentified gastropods in sixty-one. The more abundant species were *Fluminicola nuttalliana* identified in twenty-eight, *Carinifex newberryi* and *Planorbis trivolvis* in twenty each, and *Neritina reclivata* in fourteen. A stomach from Louisiana contained 1,575 shells of a small univalve (*Bythinella tenuipes*).

Miscellaneous Animal Food 5.8 per cent

Insects (*Insecta*—3.79 per cent) were common items of food although they were rarely taken in large quantities by the scaup ducks owing to the fact that most of the birds were taken in fall and winter, seasons when insects are not much in evidence. Nearly all of the insects were aquatic species, the beetles (*Coleoptera*) being by far the most abundant of the forms represented. Next in importance were the dragon flies (*Anisoptera*), the nymphs occurring in 126 and the adults in twenty-six. Water boatmen (*Corixidae*) were present in 149, and crawling water beetles (*Haliplidae*) in 102. Caddis-fly (*Trichiptera*) larvae and their cases were identified in seventy-three stomachs, and water striders (*Gerridae*) in fifty. The flies (*Diptera*) were best represented by the larvae of the midges (*Chironomidae*) found in forty stomachs and by the soldier flies (*Stratiomyidae*) in thirty. Only eight stomachs contained insects belonging to the order Hymenoptera.

The crustaceans (*Crustacea*—1.05 per cent) were rather poorly represented, the most common forms being ostracods, which were present in fifteen stomachs. Amphipods were eaten by twelve of the birds examined. Fourteen stomachs contained crabs, nine of which were mud crabs (*Neopanope texana sayi*).

Water mites (*Hydrachnidae*) were present in sixty-one stomachs, fresh water bryozoa (*Phylactolaemata*) in eight, fish bones, in eight, and spiders (*Araneida*) in six.

From the data herein presented it seems apparent that only a few families of plants furnish the bulk of the vegetable food for these five species of ducks. The pondweeds are by far the most important. As previously stated, undue importance may be given some items because of a large number of stomachs collected in some particular locality, for example, muskgrass, which stands second in the vegetable foods. Others taken widely over the country: water lilies, grasses (including wild rice), wild celery, frogbit and water weed, sedges, and coontail. Canvas-back and ringneck stomachs contained the only appreciable amount of wapatos. Sedges were fairly well represented, by their seeds, in the stomachs of ringnecks and redheads.

In the animal food, mollusks form the most important group, but in some instances shells may have been taken for grit in lieu of gravel and sand. Since only a small number of stomachs was collected in the warmer

part of the year it is not surprising that insects made up such a limited proportion of the food.

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BOBWHITE WINTER SURVIVAL IN AN AREA HEAVILY POPULATED WITH GREY FOXES[1]

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The data incorporated into this paper relate to an area of about five square miles which has been kept under observation from 1929 to 1933 in connection with studies on bobwhite quail (*Colinus virginianus*) winter mortality. The area is east of Prairie du Sac, Wisconsin, and more or less typifies the hilly, partially wooded agricultural country of non-glaciated southwest Wisconsin, southeastern Minnesota, and northeastern Iowa.

Wintering data on the Prairie du Sac quail populations dealt with have been published for three of the four seasons during which the studies have been carried on (Errington, 1933 c); the past season's work confirmed essentially the earlier findings and in addition was productive of other material of quite exceptional ecological interest. Broadly the 1932-33 biotic situation differed from those of previous years in that there was present not only a quail population practically at maximum density for what may be termed the carrying capacity of the environment but also a most unusual abundance of grey foxes (*Urocyon cinercoargenteus*).

The fox population figures were arrived at through careful calculations made at times when good tracking snows permitted study of cruising territories and individual habits. Quail censuses were based upon direct enumeration of birds in coveys or groups of coveys (see Errington 1933 a; 1933 c, for detailed description of technique). Field work was done mainly by Albert J. Gastrow, a resident of Prairie du Sac qualified by previous experience in the course of the Wisconsin quail investigation (Errington 1933 c) to handle duties assigned.

A fox density of 29 (27 greys, 2 reds) on 5 square miles or one per 110 acres seemed reasonably correct for December, 1932. This density apparently varied little during the winter except that the red foxes (*Vulpes fulva*), either left or were killed by hunters as were at least two greys. Perhaps, then, a total of 25 or one per 128 acres would represent a more nearly actual population for the winter. A composite of the initial quail censuses amounted to 406 birds for mid-December or one per 7.9 acres, which gives a fox-quail ratio of around 1:16.

Such a ratio might logically lead one to look for a high rate of predation, particularly in an area supporting both quail and foxes in the densities indicated. Let us scrutinize the data available, not alone for the measurement of fox depredations upon quail but for whatever glimpses of ecological significance we might be able to gain.

The preying of foxes on Prairie du Sac coveys has not been readily traceable either through study of the food habits of foxes themselves or through the "reading of sign" about quail remains discovered in the wild. Local fox stomach and fecal material examined showed no bobwhite and, in the four years that the area has been under observation, but twice has sign been found diagnostic enough to point to foxes as primary killers, though plenty of instances of foxes scavenging upon quail carrion have been

noted. Hence, in view of difficulties mentioned, it may be best to approach the problem by indirect means.

Insofar as some of the quail territories were situated where they were rarely hunted over by foxes, a comparison of winter mortality rates in foxless and fox-occupied environments may bring out something. Food and cover notations will also be included in the covey group mortality data, as the character of the environment has a profound effect upon the incidence and severity of predation (Errington 1931 a; 1931 b; 1933 b; 1933 c; Leopold, 1933, chaps X to XII).

The predator population, aside from the foxes was moderately high. Red-tailed hawks (*Buteo borealis*) were common, and Cooper's hawks (*Accipiter cooperi*) appeared in late winter. A pair of great horned owls (*Bubo virginianus*) nested and one or two more frequented the area boundaries. There were also one or two barred owls (*Strix varia*) and several long-eared (*Asio wilsonianus*) and screech owls (*Otus asio*); unknown numbers of weasels (*Mustela*), dogs and house cats.

FOXLESS TRACTS

Group I. Food: corn in shocks, but removed by late winter. Cover, excellent in quality but too far from feeding grounds. Count of 22 quail December 18; 20 on March 9; 17, March 23. Loss of 5 in 95 days. Evidence that the March mortality (remains of one bird found) was due to food shortage combined with attacks by a Cooper's Hawk.

Group II. Food, excellent (largely achenes of the lesser ragweed, *Ambrosia artemisiifolia*, and soybeans). Cover deficient both as to distribution and quality. December 12, 28 quail; January 5, 25; February 14, 24; March 23, 22. Loss of 6 in 101 days. Quail represented in 5 of 50 pellets from a great horned owl stationed in the covey territory.

Group III. Food, excellent (achenes of lesser ragweed and smartweeds, *Polygonum*) Cover good including a long brushy fence row adjacent to food sources. December 9, 13 birds; April 1, 11. Loss of 2 in 113 days. Remains of one bird hinted the work of a Cooper's hawk which had been seen about this time.

Total mortality on the foxless tracts: 11 out of an original 63, or 17.5% over an average period of 101 days.

FOX-OCCUPIED TRACTS

Group IV. Food and cover balance adequate. December 2, 21 birds; December 18, 22 (possibly influx of a survivor from V); March 22, 19. Loss of 2 (leaving out of consideration the one gained) in 110 days.

Group V. Food excellent (corn and soybeans). Cover poor. November 26, 12 birds; December 18, 6; January 3, none left. Mortality probably not far from complete. One kill by great horned owl found, and another apparently by the same raptor. The rather small covey territory was ranged by 4 grey foxes and one red in mid-December. It may be remarked that the covey of corresponding position last winter likewise suffered virtual annihilation (Errington, 1933 c, group XXXII). This environment for quail is truly vulnerable, seemingly by reason of cover scarcity rendered acute by horned owl and fox pressure.

Group VI. Food and cover adequate. December 16, 13 birds; March 25, 11. Loss of 2 in 99 days. The covey in this territory last winter starved out (Errnigton 1933 c, group XLII). This season corn left in shocks made the land quail-habitable.

Group VII. Food excellent (popcorn and ragweed). Cover good. December 16, 49 birds in 3 coveys (21 + 12 + 16); January 27, 47 (19 + 11 + 17); February 18, 45 (18 + 13 + 14); March 25, 44 (16 + 13 + 15). Loss of 5 in 99 days. Fox population very heavy in the general territory of the three coveys.

Group XIII. Food (soybeans and ragweed) and cover balance good. November 26, 33 birds in 2 coveys (18 + 15); February 14, 33 (coveys, after continual interchange of members, had combined); March 21, 29 (16 + 13). Loss of 4 in 115 days. One bird taken by a horned owl; another seen in possession of a red-tailed hawk but feather evidence on a highway nearby may signify that the victim had first been struck by traffic.

Group IX. Food (grain in a farmyard) and cover balance good. About 22 birds October 19; December 7, 21; January 27, 19; February 23, 17; March 25, 17. Loss of 5 in 157 days. One killed by a grey fox; two by motor traffic.

Group X. Food largely squirrel-opened acorns, also soybeans and ragweed. Cover only fair. November 9, 27 birds; December 20, 24; February 14, 24; March 18, 22; March 22, 21; April 1, 20. Loss of 7 in 143 days. Bones of quail in 3 of 36 pellets from a pair of horned owls leaving conspicuous sign in the territories of groups VIII, IX, and X.

Group XI. Food (soybeans and ragweed) and cover well balanced. December 20, 41 birds in 3 coveys (18 + 14 + 9); March 22, 39 (15 + 14 + 10). Loss of 2 in 92 days.

Group XII. Food mainly ragweed and corn, supplemented by squirrel-opened acorns and some black locust beans. Cover very good, as a whole. December 12, 125 birds in 7 coveys (16 + 18 + 21 + 26 + 12 + 14 + 18); January 28, 117 (16 + 14 + 19 + 21 + 12 + 13 + 22); March 28, 111 (16 + 13 + 18 + 19 + 11 + 12 + 22). Loss of 14 in 104 days.

Total mortality on the fox-occupied tracts: 53 out of an original 343, or 15.5 per cent over an average period of 107 days.

From the data, then, we may see that the presence or absence of foxes in various parts of the Prairie du Sac area did not appear to make any appreciable difference so far as net winter survival of the quail population was concerned; indeed the quail in foxless tracts lost at a slightly higher rate than those living in territories fox-occupeid.

This is not to be construed as meaning that foxes do not get quail or that the preponderance of quail losses from predation may, as a matter of course, be charged to the horned owl, the Cooper's hawk, or some other mammalian or avian predator species present in the area. Nor is one to gain the impression that the pressure of specific predators may be expressed as constant values in the bobwhite environmental equation, irrespective of what constancy there may be, however, in net predator pressure for the aggregate of species and upon given quail densities living in habitats of given quail carrying capacities.

Predation being largely dependent upon availability of prey (Errington 1932; 1933 b; McAtee, 1932), which is in turn conditioned by the prey species abundance, conspicuousness, escape facilities as well as their size, strength, agility, and alertness, we can readily appreciate that the capture of a quail by most predator species, especially mammals and slower hawks, is hardly as simple as the capture of a mouse or a rabbit. The bobwhite is prized by hunters for its sporting qualities—hiding ability and explosive, skillful flight and is adept at taking care of itself individually under favor-

able living conditions; winter vulnerability of vigorous, seasoned populations to predation may be said to reflect more than anything else inadequacy of environment to accommodate existing densities.

The relatively high average 15.8 per cent loss suffered by the Prairie du Sac quail (winter losses for strongly situated populations personally studied have rarely exceeded 6 per cent) merely make manifest the topheavy status of the population. The predation loss for the winter of 1931-'32 was carefully computed at 15.3 per cent for the same area and for the similar density of a quail per 8 acres.

This indicates that the greater vulnerability of the population is correlated with population density and environmental carrying capacity much more than with the predators that happen to be co-occupants of the area. In view of the fact that predation loss rates and bobwhite densities have been not far from identical during two consecutive winters, while the composition of the predator factor (compare with Errington 1933 c, area ''G'') has differed materially, we may even incline toward a thesis that, within ordinary limits, the kinds and numbers of native flesh-eaters may not be of much consequence in the winter survival of wild northern bobwhite population. Additional data pertaining to this concept are being organized for later publication.

North-central quail observational areas apparently are capable of wintering only about so many birds, their carrying capacities—high or low —varying according to food and cover combinations and the distribution of covey territories. If the environment is weak for the birds it has, the surplus has a way of becoming reduced; perhaps through the agency of horned owls, perhaps foxes, perhaps several species collectively, maybe through causes entirely unknown. At any rate, as long as there is a population surplus whatever may be its density level, its status is unstable and the aggregate pressure of the environment may be expected to force it down.

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PSEUDOMONAS RHIZOGENES R.B.W.K. & S.; ITS HOST RELATIONS AND CHARACTERISTICS[1]

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In 1928 Riker, Banfield, Wright, and Keitt (14) reported in a preliminary article that hairyroot could be induced by an organism apparently distinct from *Pseudomonas tumefaciens* Sm. & Town. At an earlier date, 1911, Smith, Brown, and Townsend (22) stated that they had isolated an organism from hairyroot that seemed different from *Ps. tumefaciens.* They, however, called the hairyroot organism a strain of the crowngall organism, but suggested that later work might prove it to be a distinct species. Up to 1925, all malformations on the roots of apple trees were considered as crowngall. At this time and later, Riker and Keitt (11) (13) and Muncie (8) showed that only a small percentage of the root knot on apples examined was true crowngall, and that the other was largely excess callus formation caused by poorly made grafts. Following this discovery, Riker and Muncie (12) recommended careful fitting of grafts, and Melhus, Muncie and Fisk (7) suggested the wedge graft for the control of callus knot. Further trials reported by Riker, Keitt and Banfield (15) showed that a light grade of adhesive tape used as a wrapper for grafts was also beneficial in the control of callus knot.

All of this work, however, did not explain such malformations as hairyroot and woolly-knot found at the unions of piece-root grafted apple trees. As was previously reported, Riker, Banfield, Wright and Keitt (14) offered further evidence that hairyroot might be caused by an organism distinct from *Ps. tumefaciens.* In 1930 Muncie and Suit (9) confirmed Riker and his co-workers (14) in the opinion that hairyroot was induced by a seemingly different organism, but refrained from naming the organism pending further studies. During the same year Riker, Banfield, Wright, Keitt and Sagen (16) presented more specific descriptive data and named the organism causing hairyroot, *Phytomonas rhizogenes* n. sp.

On the other hand Siegler (17), (19), (20) maintained that the hairyroot organism was *Pseudomonas tumefaciens* and should be designated the apple strain. Brown (2) also showed that the apple strain of *Ps. tumefaciens* produced hairyroot. In subsequent papers Siegler and Piper (18), (21) again maintained that *Ps. rhizogenes* is the apple strain of *Ps. tumefaciens.* This uncertainty as to the identy of the pathogen causing hairyroot made it seem advisable to make further study of the problem.

The purpose of this paper is to present results of investigations made over a period of three years on the natural occurrence, host range, and specific differences of the hairyroot and crowngall pathogens, and on certain factors and conditions influencing the amount of hairyroot in so far as they contribute to a better understanding of crowngall and hairyroot as induced by separate organisms. A tabulation of the differences attributed to *Ps. tumefaciens* and *Ps. rhizogenes* showed differences that seem to be sufficient to justify the setting out of a new species. The difference in effect on the host as expressed in the symptoms, is not less significant than the differences found in the cultural response. With one organism galls are formed and with the other only hairyroot develops.

DISTRIBUTION AND PREVALENCE OF HAIRYROOT

Hairyroot[3] is most noticeable on one-, two- and three-year-old nursery apple trees. As far as records are available nothing is known about the prevalence of hairyroot on a large number of varieties of apple and other species of plants grown in the nursery.

SURVEY OF APPLE VARIETIES

The results of a survey of 20 varieties of apple are presented in table 1. This survey was made during the fall of 1929 and 1930 at nurseries in five states. The results show that the percentage of hairyroot varies from 1.7 per cent on Delicious apple in Kentucky to 45.2 per cent on Wealthy apple in Oklahoma. Hairyroot was found on apple trees in each of the five states. A higher percentage of hairyroot was found in Kansas and Oklahoma than in Iowa, Kentucky, and Nebraska. It is probable that a longer growing period together with a more rapid growth of the tree is conducive to the presence of a larger amount of hairyroot in the southern part of the country. It is shown also that the percentage of hairyroot on two-year-old trees is

[3] An examination of many apple trees in a number of nurseries indicated that several forms of hairyroot existed. Three forms considered to be induced by *Ps. rhizogenes* are (1) clusters of fleshy roots, (2) woolly knots, and (3) clusters of short rootlets on aerial parts of the trees.

Form "A" hairyroot is fleshy rooted without a noticeable swelling. When young, this formation is a slight, soft swelling, which develops into the fleshy roots, and occurs only at the point of inoculation. A fully developed specimen of form "A" hairyroot has many fleshy roots, which may be eight to 10 inches long. This symptom almost always lasts throughout the first season. Typical specimens are shown in Plate I-A. When occurring naturally, this form is, in most cases, found on the underground parts of the tree, either at the union or at the crown.

Form "B" hairyroot occurs on the underground parts of the tree and is normally found at the graft union during the second growing season of the tree. When trees have been inoculated the growth is found at the point of inoculation. Form "B" hairyroot corresponds to the "hairy" or "woolly" knot of many writers. A distinct swelling is present, which is variable in size and shape sometimes three or more inches in diameter. The surface of the swelling is covered with a corky layer, and is somewhat convoluted. The texture is variable but most frequently it had a hard woody interior and a soft outer layer. From this swelling arise many roots, which are fibrous, branched, and sometimes two feet long. Form "B" is shown in Plate I-B.

Infection on the aerial parts of a tree shows as form "C". This symptom is usually found on the parts of the host above ground. In appearance, form "C" is a hemispherical swelling, which may be elongated. This swelling is soft and usually brownish in color. It is made up of numerous rootlets about one or two millimeters long. When put under favorable conditions these rootlets will grow and become fleshy. Form "C" hairyroot, induced by inoculating *Ps. rhizogenes* into dwarf stone tomato, is shown in Plate VI-A-B.

practically the same as that on two-year cut-back trees when results for the same year are compared.

From this survey of 20 of the leading varieties of apple, it is apparent that they differed widely in the amount of infection. The Wealthy showed the most infection, averaging about 25 per cent hairyroot. Yellow Transparent, Duchess and Gano are also varieties that appeared to be quite generally infected. The variety showing the least infection was the Stayman which averaged about five percent hairyroot. The varieties Delicious and Jonathan also were low.

In examining table 1 for the prevalence of the different forms of hairy-

TABLE 1. *Results of surveys at nurseries in five states to determine the distribution and prevalence of hairyroot on different varieties of apple trees.*

State	Variety	Age	No. observed	Percentage hairyroot	Trees with hairyroot "A"	Trees with hairyroot "B"	Year
Kentucky	Delicious	2 yrs	355	1.7	3	3	1929
,,	Grimes Golden	,,	484	4.1	6	14	,,
,,	Stayman	,,	626	4.6	8	21	,,
,,	Wealthy	,,	428	10.9	15	32	,,
Oklahoma	Baldwin	,,	271	34.6	23	71	,,
,,	McIntosh	,,	143	32.8	17	30	,,
,,	Jonathan	,,	129	31.7	11	30	,,
,,	Winter Banana	,,	196	31.1	23	38	,,
,,	Wealthy	,,	243	45.2	41	69	,,
Kansas	,,	,,	2913	24.7	216	505	1930
,,	Yellow Transparent	,,	2901	17.4	167	339	,,
,,	N. W. Greening	,,	968	29.6	83	204	1929
Nebraska	Wealthy	,,	1403	5.8	30	52	1930
,,	Whitney	,,	1296	5.0	25	41	,,
,,	Yellow Transparent	,,	1127	4.4	23	27	,,
,,	Duchess	,,	287	10.1	14	15	,,
,,	Wolf River	,,	702	12.9	23	68	1929
,,	Winesap	,,	1104	10.1	37	75	,,
,,	Stayman	,,	1149	6.8	24	55	,,
,,	Wealthy	,,	959	32.4	111	200	,,
Iowa	Pewaukee	,,	434	17.9	31	47	1930
		2 yr.-cut-back					
,,	Bayfield	,,	394	8.6	12	22	,,
,,	Jonathan	,,	429	4.4	7	12	,,
,,	Delicious	,,	457	7.4	15	19	,,
,,	Red Astrachan	,,	539	12.2	27	39	,,
,,	Ben Davis	,,	508	18.3	36	57	,,
,,	Gano	,,	511	23.4	47	73	,,
,,	Wolf River	2 yrs.	803	3.3	11	16	,,
,,	Wealthy	,,	1632	4.1	32	35	,,
		2 yr.-cut-back	1104	33.2	145	222	,,
,,	Duchess	,,	1113	31.9	97	194	1929
,,	Whitney	,,	521	21.1	43	67	,,
,,	Yellow Transparent	,,	910	32.6	102	195	,,

root, it is found that form "B" predominates at the time the trees are dug at the nursery. A comparison of forms "A" and "B" hairyroot shows that about one-third of the hairyroot present on apple trees is of the current season infection, or form "A."

Relation of woolly aphid injury to prevalence of hairyroot

A limited amount of data has been obtained which suggests a possible relationship between the presence of woolly aphid injury and hairyroot. These data are shown in table 2. With the exception of the data on apple seedlings, all results were obtained by nursery surveys made during the fall of 1930. The most direct evidence of an increase of hairyroot caused by woolly aphid injury was obtained in the study on two-year apple seedlings. In this case only 2.6 per cent of seedlings free from woolly aphid had form ''A'' hairyroot. The seedlings which were infested with woolly aphids showed 24.4 per cent of the seedlings with form ''A'' hairyroot. The data in table 2 show that as the percentage of trees infested with woolly aphids drops, the amount of hairyroot decreases. Plate II-A shows a typical example of hairyroot associated with woolly aphid injury, from which *Ps. rhizogenes* was isolated.

TABLE 2. *Relation of woolly aphid (Eriosoma lanigera) injury to the percentage of form ''A'' hairyroot found on apple trees.*

State	Apple varieties	Percent-age of woolly aphid	No. observed	No. hairyroot form ''A''	Percent-age of hairyroot
Iowa	Two-year apple seedlings*	None	300	8	2.6
,,	,, ,, ,, ,,	100	450	110	24.4
,,	Red Astrachan	20	539	66	12.2
,,	Ben Davis	30	508	93	18.3
,,	Gano	40	511	120	23.4
,,	Jonathan	3	429	19	4.4
,,	Wealthy	3.5	1632	35	2.1
Kansas	,,	14	2913	216	7.4
,,	Yellow Transparent	4	2901	167	5.7
Nebraska	Wealthy	None	1403	29	2.1
,,	Yellow Transparent	,,	1127	23	2.0

* The data on apple seedlings were obtained from plantings on the experimental plots at Ames, Iowa.

SURVEY OF OTHER NURSERY STOCK

Since hairyroot was found to be so prevalent on nursery apple trees, it seemed worthwhile to observe the condition of other nursery stock. Most of the data were obtained in the field as the stock was being dug; although, in a few cases notes were taken after the plants had been placed in storage. A list of the hosts examined and the results obtained is given in table 3. Hairyroot was found on snowberry, honeysuckle, two species of Spiraea and the floribunda crab, the percentages of infestation ranging from 1.5 to 4.2.

The hairyroot found on snowberry resembled somewhat the form ''B'' hairyroot. An hemispherical swelling about one-half to three-fourths of an inch in diameter with a hard woody interior occurred on the main root from which clusters of four to eight fibrous rootlets originated. In the case of honeysuckle, the nodes of the underground stem were somewhat enlarged and in this tissue a number of small roots originated. The two species of Spiraea bore hairyroot which was practically the same in appearance. This hairyroot was of two different forms. Both forms occurred on the underground parts. One form was characterized by numerous small, fibrous roots coming from a point on the main root, while the other form had a small

swelling, about one-half inch in diameter, from which the numerous fibrous roots originated. It was considered that these symptoms were the same, except that the form having the swelling was older. Plate II-B shows hairy-root as it occurs on Spiraea.

TABLE 3. *Results of surveys at nurseries in Iowa and Nebraska to determine the occurrence of hairyroot upon general nursery stock in 1929 and 1930*

Host	No. observed	No. plants with hairyroot	Percentage with hairyroot
Hydrangea arborescens L.	1000	0	0
Lilac (*Syringa vulgaris* L.)	1000	0	0
Euonymus atropurpureus Jacq.	1000	0	0
Cornus stolonifera Michx.	1000	0	0
Symphoricarpus racemosus Michx.	900	16	1.7
Spiraea vanhouttei Zabel.	925	26	2.8
Spiraea prunifolia Sieb. & Zucc.	887	14	1.5
Lonicera tartarica L.	780	25	3.2
Plum seedlings (*Prunus domestica* L.)	625	0	0
Honey locust seedlings (*Gleditsia triacanthos* L.)	520	0	0
Ash seedlings (*Fraxinus americana* L.)	500	0	0
American elm seedlings (*Ulmus americana* L.)	500	0	0
Mulberry seedlings (*Morus alba* L.)	500	0	0
Cotoneaster seedlings (*Cotoneaster acuminata* Lindl.)	500	0	0
Caragana seedlings (*Caragana arborescens* Lam.)	500	0	0
Russian olive seedlings (*Elaeagnus angustifolia* L.)	500	0	0
Peach seedlings (*Prunus persica* Sieb. & Zucc.)	600	0	0
Latham raspberry (*Rubus idaens* L.)	520	0	0
Cumberland raspberry (*Rubus occidentalis* L.)	505	0	0
Early Richmond cherry (*Prunus cerasus* L.)	530	0	0
English Morello cherry (*Prunus cerasus* L.)	500	0	0
Floribunda crab (*Pyrus pulcherrima* Aschers. & Graebn.)	470	20	4.2

ASSOCIATION OF PSEUDOMONAS RHIZOGENES WITH HAIRYROOT ON NURSERY STOCK

Various types of hairyroot formation were found upon snowberry, honeysuckle, Spiraea, and crab apple as well as on apple, and isolations were made from each of these plants to establish the infectious nature of hairyroot. Isolations were made also from hairyroot on different varieties of apple which had been collected in Kentucky, Oklahoma, Kansas, Nebraska and Iowa.

METHOD OF ISOLATION

The specimen was scrubbed in running water with a fairly stiff brush. The rootlets were then cut off at the base and the remaining overgrowth was flooded with alcohol which was allowed to burn off. Then, with a sterile scalpel, approximately one cubic centimeter of the corky layer from which the roots arise was cut out. This piece was put into a sterile petri dish and five cubic centimeters of sterile water added. The tissue was finely macerated with a sterile scalpel and allowed to stand for one-half to two hours in the water, so that the bacteria might diffuse from the cut tissue. One cubic centimeter of the suspension was added to 30 cc. of bile agar as described by Patel (10) and incubated at 28°C. Typical colonies of *Ps. rhizogenes* usually appeared after two to four days incubation. Colonies of *Ps. rhizogenes* are similar to those of *Ps. tumefaciens* with the exception that they are inclined to be more opaque and of a whitish color, while those of *Ps.*

tumefaciens are translucent. Both organisms exhibit a darker center in the colony, but it is more pronounced in the case of *Ps. tumefaciens*. Out of thirty trials in which the hard woody interior of the form ''B'' hairyroot was used, the organism was recovered in only one case, and out of 30 trials on the corky layer of the same specimens, the organism was recovered in each case.

The usual practice in the isolations was to make two distinct trials from each specimen and three plates of each trial. This made six plates representative of the bacterial flora of the two pieces of a single hairyroot formation. After the usual incubation, two typical colonies were taken from each plate and transferred to peptone-dextrose agar slants, which were used as standard for stock cultures and transfer work. Thus it is seen that 12 cultures were obtained from each normal hairyroot specimen. These twelve cultures were used as a source of inoculum for the inoculation of sugar beets.

Sugar beet (*Beta vulgaris* L.) was adopted as a differential host because both *Ps. tumefaciens* and *Ps. rhizogenes* produce typical symptoms at the crown within one month. Siegler (19) and Muncie and Suit (9) have shown that this host is susceptible to both organisms. If, after one month, any of the inoculated sugar beets showed the formation of hairyroot, the culture used as inoculum was regarded as being *Ps. rhizogenes*. The results of isolations made during 1930 from five species of ornamental shrubs and eight varieties of apple are given in table 4.

TABLE 4. *Results from investigations on the association of an organism with hairy-root found on certain hosts*

Host	No. specimens hairyroot	No. isolations	Presence of	
			Ps. tume-faciens	*Ps. rhizo-genes*
Symphoricarpus racemosus	16	32	0	0
Spiraea vanhouttei	26	52	0	30
Spiraea prunifolia	14	28	0	8
Lonicera tartarica	25	50	0	0
Floribunda crab	20	20	0	20
Duchess apple (Ia.)	6	12	0	12
Ben Davis apple (Ia.)	4	8	0	7
Grimes Golden apple (Ky.)	3	9	0	7
Delicious apple (Ky.)	3	6	0	6
McIntosh apple (Okla.)	4	8	0	8
Jonathan apple (Okla.)	3	6	0	5
Winter Banana apple (Okla.)	3	6	0	5
Wealthy apple Form A	125	250	0	241
Wealthy apple Form B	87	174	0	103

HAIRYROOT ON DIFFERENT VARIETIES OF APPLE

Isolations from form ''A'' hairyroot occurring on eight different varieties of apple and one variety of crab, have yielded *Ps. rhizogenes* from every specimen. However, in a few cases, both trials from the same specimen were not positive.

An isolation study was made of all hairyroot obtained throughout the year on Wealthy apple. Table 4 shows that when isolating from Form ''A''

hairyroot, 241 out of a possible 250 isolations for *Ps. rhizogenes* were positive. In the trials on Form "B" hairyroot, only 103 out of 174 isolations were positive for *Ps. rhizogenes.* This shows that it is more difficult to isolate the causal organism from Form "B" than from Form "A" hairyroot. In this study it was found that 25 of the Form "B" hairyroot were negative for both isolation trials, although organisms which resembled *Ps. rhizogenes* were obtained in some cases. An explanation of the negative isolation trials is not evident, although it is possible that the bacteria may have disappeared from these older growths.

HAIRYROOT ON CERTAIN ORNAMENTAL SHRUBS

Isolation trials on the hairyroot of ornamentals were variable. Table 4 shows that *Ps. rhizogenes* was recovered only from hairyroot on the two species of Spiraea. The hairyroot on snowberry resembled Form "B" hairyroot. Colonies resembling *Ps. rhizogenes* were obtained from 12 of the snowberries but repeated inoculations into sugar beet gave only negative results. The symptoms of hairyroot on the honeysuckle occurred at the nodes and it is possible that this was not hairyroot. Sterile plates were obtained from 20 of the honeysuckle specimens and bacteria from the other five; but only negative results were obtained from inoculations with these.

In the case of the two species of Spiraea, an organism which caused hairyroot on sugar beet was isolated from several of the specimens. The trials on *Spiraea vanhouttei* gave 30 positive inoculations in 52. Sterile plates were obtained from three specimens, and apparently non-pathogenic organisms from five others. Therefore, of 26 growths obtained, 18 were shown to be caused by *Ps. rhizogenes*. The results of isolations from 14 specimens of hairyroot on *Spiraea prunifolia* showed *Ps. rhizogenes* in only 8 of 28 trials. All the positive results were from four specimens. Seven specimens yielded no organisms and three others showed the presence of organisms, which resembled *Ps. rhizogenes* but were not pathogenic.

The above studies indicated that *Ps. rhizogenes* was associated with hairyroot not only on the apple but also on other ornamental nursery stock.

THE INFLUENCE OF ENVIRONMENTAL AND HOST CONDITIONS ON INFECTION BY PSEUDOMONAS RHIZOGENES

Results of inoculations with the hairyroot organism over a period of two years were not always consistent. As an explanation for these differences was not forthcoming, a study was made of three factors that might cause this variation.

RELATION OF ACIDITY OF HOST PLANT EXTRACT TO INFECTION BY PSEUDOMONAS RHIZOGENES

A study was made of various hosts used for inoculation to determine the influence of acidity on the development of hairyroot symptoms. Herbaceous hosts were ground in a food chopper and the sap extracted at 10,000 pounds pressure with a hydraulic press. In the case of the woody hosts, the live stems were ground in a Wiley mill and 20 cc. of conductivity water added to each 100 grams of ground substance. This was allowed to stand for 72 hours at 10°C. The liquid was then extracted and determinations made within one hour. All determinations of pH were made in duplicate from two separate samples, using the quinhydrone electrode. The pH value obtained for the different host extracts is shown in table 5. A comparison of values obtained does not indicate a relation between active acidity and

susceptibility of the hosts used except possibly in the case of the two varieties of tomato, Bonny Best and Dwarf Stone. Form "C" hairyroot developed on the plants of the variety Dwarf Stone but not on those of the variety Bonny Best.

INFLUENCE OF SOIL TEMPERATURE, RAINFALL, AND TIME OF SEASON UPON INFECTION BY PSEUDOMONAS RHIZOGENES

During the summers of 1928 and 1929 various inoculation studies suggested that certain environmental factors might have an influence on the percentage of hairyroot obtained. Consequently during the summer of 1930 a study was made of the soil temperature, rainfall, and time of season as they affected the percentage of hairyroot induced by *Ps. rhizogenes* when inoculated into Wealthy apple grafts and peach seedlings. Soil temperatures were recorded on a Friez soil thermograph with the bulb buried four inches below the surface of the soil. The rainfall records were obtained from the

TABLE 5. *A comparison of the acidity of host plant and its susceptibility to Ps. rhizogenes*

| | pH value | | | |
Host	Sample 1	Sample 2	Average	Pathogencity of Ps. rhizogenes
Sugar beet	5.39	5.44	5.41	HR+*
Paris daisy	5.62	5.37	5.49	HR+
Bryophyllum	5.13	5.40	5.26	HR+
Tomato, Dwarf Stone	5.54	5.48	5.51	HR+
Tomato, Bonny Best	6.2	6.0	6.1	O
Peach seedling	5.13	5.14	5.13	HR+
Apple seedling	5.26	5.25	5.25	HR+
Mulberry seedling	5.38	5.34	5.36	HR—
Carangana seedling	4.87	4.87	4.87	HR—
Cotoneaster seedling	5.27	5.28	5.27	HR—
Russian olive seedling	5.21	5.28	5.27	HR+
Elm seedling	5.38	5.38	5.38	O
Locust seedling	5.43	5.38	5.40	HR—
Ash seedling	4.80	4.81	4.80	O
Snowberry	5.27	5.27	5.27	HR+
Honeysuckle	5.09	5.07	5.08	HR+
Spiraea vanhouttei	5.32	5.27	5.29	HR+
Wealthy apple	5.23	5.23	5.23	HR+

* The response from inoculations is indicated as follows:
    HR+ = highly pathogenic
    HR— = slightly pathogenic
    O = no reaction

Weather Bureau Sub-Station at Iowa State College. A combined summary of weekly rainfall and average weekly soil temperature is shown graphically in figure 1. The weekly soil temperature was obtained by averaging the temperatures obtained every two hours throughout the day and night. In the graph, the data given for each date are for the week following that date. It is to be noted that the rainfall from June 16 to September 25 was very slight with a heavy rain the week following September 22. The highest soil temperature occurred during the week of July 21.

Inoculations were made on 15 Wealthy apple grafts and 15 peach seedlings at the beginning of each week, starting on June 16 and continuing

until August 25 when the last series was made. Cultures No. 1 and 2 of *Ps. tumefaciens* and No. 9, 12 and 15 of *Ps. rhizogenes* were used in this study. A summary of the results obtained from inoculation at weekly intervals with these cultures, is given in table 6. Final notes were taken on October 23 and 24, 1930.
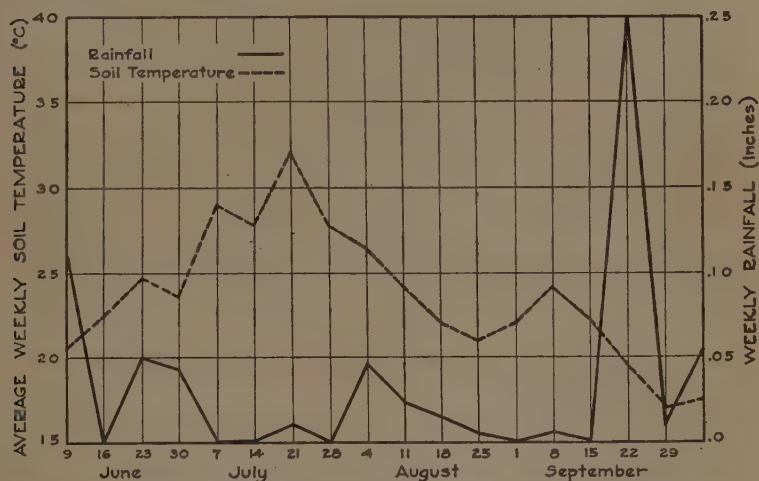
Fig. 1. Average weekly soil temperature and rainfall, June 9, to October 1, 1930 at the Experimental Plots, Ames, Iowa.

TABLE 6. *Percentage of infection obtained from inoculation at week intervals of Wealthy apple grafts and peach seedings with Ps. tumefaciens and Ps. rhizogenes*

Host		Culture			Date of inoculation								
					June			July				August		
					16	23	30	7	14	21	28	4	11	25
Wealthy apple	,,	1—	*Ps.*	*tum.*	100	40	67	80	60	100	40	80	27	0
,,	,,	2—	,,	,,	87	74	80	60	60	100	60	80	47	0
,,	,,	9—	*Ps.*	*rhiz.*	100	100	100	87	80	47	60	80	0	0
,,	,,	12—	,,	,,	100	100	100	100	80	100	74	80	0	87
,,	,,	15—	,,	,,	100	100	100	100	67	100	80	80	0	80
,,	,,	Ck.			0	0	0	0	0	0	0	0	0	0
Peach seedling	,,	1—	*Ps.*	*tum.*	87	100	100	87	100	100	100	100	100	100
,,	,,	2—	,,	,,	100	100	100	100	100	100	100	100	100	100
,,	,,	9—	*Ps.*	*rhiz.*	40	67	67	67	0	14	14	0	34	40
,,	,,	12—	,,	,,	60	40	80	67	20	0	34	74	54	80
,,	,,	15—	,,	,,	60	60	80	47	34	0	27	54	20	60
,,	,,	Ck.			0	0	0	0	0	0	0	0	0	0

The results obtained from inoculations on Wealthy apple grafts are somewhat variable. Almost complete infection was obtained with *Ps. rhizogenes* to July 10. After this date, the results were variable and somewhat doubtful toward the latter part of August. The data strongly indicate

that moisture conditions and growth rate of the host plant are more important factors in relation to the production of hairyroot by its causal organism, than is temperature. Figure 1 shows that the soil temperature during the latter part of August was approximately the same as in June when good infection was obtained. Also the percentage of hairyroot from inoculations made in July when the soil temperature was highest, was lower than in June and slightly higher than from the inoculations in August. From this study it seems that soil temperature is not a factor influencing hairyroot production by the causal organism, under conditions of an extremely dry season. However, under conditions of a season with the normal supply of moisture, the soil temperature might be a factor.

It would appear that moisture was a limiting factor. After July 14 the top five inches of soil was so dry that it would not hold its shape when pressed into a ball. Later during August, the soil was powdery dry to a depth of nearly five inches. This lack of moisture may be the cause of the variation obtained from inoculations made during July and August. The inoculations were examined every two weeks. Very small rootlets about one or two millimeters long and typical of Form "C" hairyroot were the only symptoms until after the week of September 22 when 2.45 inches of rain fell. This rain soaked the ground and when final notes were taken on October 23 typical form "A" hairyroot was formed from every inoculation. Only short rootlets were present before the rain when the soil was extremely dry.

The study made on peach seedlings gave practically the same results as that on apple except that the smallest percentage of hairyroot induced by *Ps. rhizogenes* was during the time that the soil temperature was highest. Throughout the season the inoculations with *Ps. tumefaciens* on peach seedlings showed 100 per cent infection, except in two cases.

These results tend to show that moisture is of prime importance in hairyroot formation by *Ps. rhizogenes*. The development of the host may have a secondary effect. Towards the latter part of the summer and fall, the trees are not in as rapid a state of growth and food manufacture as in the early summer and possibly not as susceptible.

HOST RANGE OF PSEUDOMONAS RHIZOGENES

Riker, and his co-workers (16) have reported positive results from inoculations with *Ps. rhizogenes* on tomato (*Lycopersicon esculentum* Mill.), tobacco (*Nicotiana Tabacum* L.), apple (*Pyrus malus* L.), rose (*Rosa setigera* Michx.), honeysuckle (*Lonicera Morrowi* Gray), sugar beet (*Beta vulgaris* L.), bean (*Phaseolus vulgaris* L.) and Paris daisy (*Chrysanthemum frutescens* L.). In order to make a further study of the host range and to test the pathogenicity of *Ps. rhizogenes* obtained from two species of Spiraea, a series of inoculation studies were made in the greenhouse and field.

SOURCE OF CULTURES AND METHOD OF INOCULATION

The sources of the 19 cultures used in these studies are given in table 7.

For inoculation purposes, only plants in good growing condition and free from disease were used. Inoculation was accomplished by taking some of the bacterial growth from an agar slant and pricking this mass of bacteria into the plant tissue. For this work a spear-point needle was found to be most satisfactory. All inoculations of herbaceous plants were made on the

stem internode with the exception of sugar beet, which was inoculated at the crown. All inoculations except those on sugar beet were put in a moist chamber for three days following the inoculation to allow the organism to become established. In the field, inoculations were made on other possible

TABLE 7. *Source of cultures of Pseudomonas rhizogenes, Pseudomonas tumefaciens and Bacillus radiobacter used in inoculation studies*

Culture no.	Organism	Host	Location	Date	Isolated by
1	*Ps. tum.*	Apple	Iowa	1926	Muncie
2	,, ,,	,,	,,	1925	Patel
3	,, ,,	,,	,,	,,	Muncie
4	,, ,,	Dahlia	Indiana	1928	,,
5	,, ,,	Sycamore maple	Michigan	1929	Suit
6	*Ps. rhiz.*	Duchess apple	Iowa	,,	,,
7	,, ,,	Grimes apple	Kentucky	,,	,,
8	,, ,,	Jonathan apple	Oklahoma	,,	,,
9	,, ,,	Wealthy apple	Iowa	,,	,,
10	,, ,,	Ben Davis apple	,,	,,	,,
11	,, ,,	*Spiraea prunifolia*	,,	1930	,,
12	,, ,,	,, ,,	,,	,,	,,
13	,, ,,	*Spiraea vanhouttei*	,,	,,	,,
14	,, ,,	,, ,,	,,	,,	,,
15	,, ,,	,, ,,	,,	,,	,,
16	,, ,,	Single cell isolation from #9		1930	,,
17	,, ,,	,, ,, ,, ,, ,,		,,	,,
18	*B. radio.**			1928	
19	,, ,,			,,	

* From Dr. N. R. Smith, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

hosts. The soil was usually removed from around the host and the inoculation made three inches below the ground line. The soil was then replaced and the row of plants hilled up with a hand plow.

INOCULATIONS ON HERBACEOUS PLANTS
GROWN IN THE GREENHOUSE

Inoculation trials on seven herbaceous hosts were carried out in the greenhouse and the results are tabulated in table 8. In examining table 8 it will be noticed that all responses whether gall or hairyroot, are modified by a + or a — which, according to the footnote, denotes the percentage of hairyroot obtained, and helps to indicate the relative degree of pathogenicity of the respective culture. Thus a response modified by + indicates that the pathogenicity of the organism on that host is above average while a reaction modified by — denotes less than average pathogenicity.

A greater number of sugar beets were inoculated than any other host, because they were used in determining the pathogenicity of the cultures isolated from different hosts. Typical symptoms of *Ps. rhizogenes* and *Ps. tumefaciens* on sugar beet are shown in Plate III-C. All cultures of *Ps. tumefaciens* and *Ps. rhizogenes* used gave over 90 per cent infection from more than 35 inoculations with each culture. *Bacillus radiobacter* gave no results.

Siegler (17) has objected to the use of tomato (*Lycopersicon esculentum* Mill.) as a differential host for determining the pathogenicity of *Ps. tumefaciens*. However, a study of a few different varieties has given some interesting results. The Bonny Best tomato which has a somewhat succulent stem has long been used in the greenhouse for crowngall inoculations. That some other variety would be better suited to greenhouse conditions was quite probable. It was finally decided that a dwarf variety of tomato such as Dwarf Stone which has a more stocky and woody stem could be more easily handled and be just as susceptible to infection. Table 8 shows that, with the Bonny Best tomato, visible infection by *Ps. rhizogenes* was not ob-

TABLE 8. *Results of inoculation of seven herbaceous plants with cultures of Ps. tumefaciens, Ps. rhizogenes and B. radiobacter*

Culture		Sugar beet	Tomato varieties		Paris daisy	Green pod stringless beans	Bryo-phyllum	Coleus
			Bonny Best	Dwarf Stone				
1—	*Ps. tum.*	G+*	G+	G+	G+	G+	G+	G+
2—	" "	G+	G+	G+	G+	G+	G+	G+
3—	" "	G+	G+	G+	G+	G+	G+	G+
4—	" "	G+	G+	G+	G+	G+	G+	G+
5—	" "	G+	G+	G+	G+	G+	G+	G+
6—	*Ps. rhiz.*	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
7—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
8—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
9—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
10—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
11—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
12—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
13—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
14—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
15—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
16—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
17—	" "	HR+	0	Pr+	Pr+	HR—	HR+	Pr—
18—	*B. radio*	0	0	0	0	0	0	0
19—	" "	0	0	0	0	0	0	0
Ck.		0	0	0	0	0	0	0

* Response from inoculations is indicated as follows:

    G = Gall   0 = No infection
    HR = Hairyroot   + = Over 50 per cent infection
    Pr = Small rootlet   — = Under 50 per cent infection

tained, but that 100 per cent infection resulted when *Ps. tumefaciens* was used. When the dwarf variety, Dwarf Stone, was used further evidence developed. *Pseudomonas rhizogenes* and *Ps. tumefaciens* both produced typical symptoms on this host. The galls induced by *Ps. tumefaciens* were just as large as those formed on the variety Bonny Best. In the case of *Ps. rhizogenes,* a cluster of small rootlets (form "C" hairyroot) was formed at the point of inoculation as shown in Plate VI-AB. Both these varieties of tomato made no response to inoculations with *Bacillus radiobacter*. Dwarf Stone tomato stems having form "C" hairyroot were buried in sand, which had been steamed at 20 pounds pressure for six hours. These stems were examined after three weeks. It was found that each of the rootlets had grown and become true roots some of which were three or four inches long. A series of tomato stems bearing galls were also buried, but no roots de-

veloped from the gall tissue. It would seem from these results that the Dwarf Stone tomato is as differential in its reaction as is the sugar beet, Paris daisy, or tobacco.

Since the first work on crowngall, the Paris daisy (*Chrysanthemum frutescens* L.) has been a host of recognized response to *Ps. tumefaciens.* Inoculations in the stem of Paris daisy showed typical crowngall and form "C" hairyroot when *Ps. tumefaciens* and *Ps. rhizogenes,* respectively, were used. No response was obtained following inoculation with *B. radiobacter.* Plate III-B shows the response of Paris daisy to the two organisms. A series of stems having crowngall and form "C" hairyroot were buried in steamed sand. After three weeks many roots were coming from the form "C" hairyroot and no roots could be found which were coming from the crowngall tissue. Plate IV-AB shows typical rooting which was obtained from form "C" hairyroot.

Green pod stringless beans (*Phaseolus vulgaris* L.) were inoculated at the nodes with the various cultures. Typical galls were produced by all cultures of *Ps. tumefaciens* used. Results from trials with *Ps. rhizogenes* gave hairyroot with every culture used, but the percentage of infection was rather low and the swelling that accompanied the hairyroot symptom was quite pronounced.

Bryophyllum calycinum Salisb. will root more rapidly than most common greenhouse plants. For this reason, it was used to determine the relation between the rooting occasionally found associated with crowngall and that rooting caused by *Ps. rhizogenes.* All cultures of *Ps. tumefaciens* and *Ps. rhizogenes* produced typical symptoms on this host. In one series of inoculations, the plants were watered heavily every day. The results obtained from this series are shown in Plate III-A. Good rooting was caused by *Ps. rhizogenes* inoculated in the internode. In the case of crowngall, no rooting was obtained, either from the gall tissue or from the host tissue immediately surrounding the gall. A second series of plants were watered every other day. At the end of the experiment galls without rooting had been induced by *Ps. tumefaciens.* The wound at the point of inoculation with *Ps. rhizogenes* resembled the check punctures. These stems were then buried in steamed sand for three weeks. The check stems showed rooting only from the nodes and none from the sterile inoculation on the internode as is shown in Plate IV-BA. Results obtained from the stems inoculated in the internode with *Ps. rhizogenes* showed good rooting at the place of insertion of the organism as is shown in plate IV-AA. No rooting originated in the crowngall tissue on the galled stems, although good rooting was obtained from the host tissue immediately surrounding the galled area.

Coleus blumei Benth. was not as susceptible to *Ps. rhizogenes* as the other hosts used in the greenhouse inoculations. All cultures of *Ps. tumefaciens* induced galls on the internode of Coleus. The inoculations with *Ps. rhizogenes* gave a low percentage of positive results. Short rootlets were produced on each plant inoculated, but not at every place of inoculation. The stems were buried in steamed sand for three weeks and no rooting was found in connection with the gall formations.

From the ease with which comparatively normal rooting developed from form "C" hairyroot, it was thought that *Ps. rhizogenes* might stimulate the rooting of cuttings, and thus be put to practical use.

INOCULATION OF HERBACEOUS AND HARDWOOD CUTTINGS
WITH PSEUDOMONAS RHIZOGENES

The readiness with which *Ps. rhizogenes* produces hairyroot on growing hosts indicates a possibility of root stimulation on cuttings, although Siegler (20) reports that the apple strain of *Ps. tumefaciens* inhibits root formation on very young apple seedlings and apple root sprouts.

A study was made of the reaction of cuttings of Bryophyllum, Paris daisy, and coleus to inoculation by *Ps. rhizogenes*. The cuttings were inoculated by needle punctures at the base using two cultures of *Ps. rhizogenes,* one isolated from apple and one from *Spiraea vanhouttei*. After the cuttings were inoculated they were placed in steamed sand and allowed to grow for 30 days. Table 9 gives the results of two series of inoculations with the three kinds of cuttings. A marked stimulation of rooting occurred in the Bryophyllum cuttings. Plate V-A shows Bryophyllum cuttings which were selected at random from the flats after 25 days. In the Paris daisy cuttings there was also a difference in favor of those inoculated, but it was not as marked as in the Bryophyllum cuttings. *Pseudomonas rhizogenes* had little effect on the Coleus cuttings. This may be due to its resistance to the hairyroot organism.

TABLE 9. *Results of inoculating Ps. rhizogenes into the base of herbaceous cuttings*

Cutting	Culture	No.	Number of cuttings with root development			
			None	Slight	Fair	Good
Bryophyllum	Check	120	20	50	55	6
,,	7	120	0	18	29	73
,,	14	120	0	8	26	86
Paris daisy	Check	100	28	15	25	32
,, ,,	7	100	15	21	24	40
,, ,,	14	100	14	0	38	48
Coleus	Check	80	0	0	6	74
,,	7	80	0	0	7	73
,,	14	80	0	0	6	74

The results obtained with herbaceous cuttings led to trials with hard wood cuttings. Cuttings of Wealthy apple, *Spiraea vanhouttei,* and one-year apple seedling were inoculated in the same manner as the herbaceous cuttings—by needle puncture at the base of the piece. All material was obtained in the fall of 1930 and put into storage until January. The cuttings were made from six to eight inches long, and surface disinfected with mercuric chloride, while the top was dipped in paraffin to prevent the drying of the tissue. After inoculations, the cuttings were set in steamed sand in the cutting bench. After 50 days had elapsed, notes were taken on callus and root development. The results of this experiment are given in table 10, and show that no inhibition of rooting occurred. In general the cuttings which showed pronounced callus formation would have been expected to root if given more time. In examining the callus formed on the different groups of cuttings, several distinct differences were noticed. Of the apple seedlings, 21 of the check cuttings developing callus showed a distinct browning of the callus, while the callus of the inoculated cuttings was light colored and seemingly in a healthier condition.

TABLE 10.   *Results of inoculating Ps. rhizogenes into the base of hardwood cuttings to stimulate their rooting*

Cutting	Culture	No.	Dead	Number of cuttings			Rooting
				Good callus	Slight callus	No. callus	
One-year-apple seedling	Check	100	0	23	34	16	27
,, ,,	7	100	0	0	25	34	41
,, ,,	14	100	0	4	24	38	34
Wealthy apple	Check	100	15	9	36	40	0
,, ,,	7	100	23	3	17	43	14*
,, ,,	14	100	32	10	17	31	10*
Spiraea vanhouttei	Check	100	38	14	15	17	16
,, ,,	7	100	37	12	10	14	27
,, ,,	14	100	29	11	14	13	33

* Small rootlets present.

Pseudomonas rhizogenes isolated originally from *Spiraea vanhouttei* caused more rooting of Spiraea cuttings than the culture of *Ps. rhizogenes* obtained from apple. Similarly *Ps. rhizogenes* from apple induced more rooting on the two kinds of apple cuttings than the same organism obtained from Spiraea. Plate V-B shows the rooting obtained on cuttings of *Spiraea vanhouttei*. A limited number of isolations have been made from the base of the inoculated cuttings which showed the best rooting and *Ps. rhizogenes* was recovered in each case, while isolation trials from the rooted check cuttings showed negative results. A distinct stimulation of rooting occurred in all cuttings used except Coleus. This would indicate that microorganisms may play some part in the rooting of cuttings.

INOCULATION OF ORNAMENTAL SHRUBS, WEALTHY APPLE GRAFTS, AND DECIDUOUS TREE SEEDLINGS

After obtaining the reaction of the various cultures of *Ps. rhizogenes* on greenhouse plants, it seemed advisable to determine their pathogenicity on the original hosts and other possible hosts under field conditions. For this study the same 19 cultures used in the greenhouse trials described in an earlier part of this paper were employed. At least 25 plants of each host were inoculated with each culture, except numbers 16 and 17, which were inoculated only on Wealthy apple grafts. Since the summer of 1930 was extremely dry, it is believed that these inoculations are more nearly an accurate test of the pathogenicity of the cultures than they would have been if the usual amount of moisture had been present. The results of the field inoculations are given in table 11.

Each culture was inoculated into 50 Wealthy scions of the current season's grafts. The results obtained showed that all cultures of *Ps. tumefaciens* and *Ps. rhizogenes* were pathogenic on Wealthy apple. No reaction was obtained with the cultures of *Bacillus radiobacter*. Form "A" hairy-root produced on Wealthy scion by *Ps. rhizogenes* is shown in Plate VI-BA.

The results with *Spiraea vanhouttei* were variable. Only one culture of *Ps. rhizogenes* isolated from apple was distinctly pathogenic on this host, while the cultures of *Ps. tumefaciens* and cultures No. 6, 7, and 8 were

TABLE 11. *Results of inoculation of ornamental shrubs, Wealthy apple grafts, and deciduous tree seedlings with Pseudomonas tumefaciens, Ps. rhizogenes, and Bacillus radiobacter*

| Culture | Wealthy apple | Ornamentals | | | | One-year-old seedlings | | | | | | | |
		Spiraea van-houttei	Honey-suckle	Snow-berry	Apple	Elm	Locust	Ash	Mul-berry	Peach	Cara-gana	Russian olive	Coton-easter
1— Ps. tum.	G+*	G—	G+	G+	G—	0	0	0	0	G+	G—	G+	G—
2— ,,	G+	G—	G+	G+	G—	0	0	0	0	G+	G—	G+	G—
3— ,,	G+	G—	G+	G+	G—	0	0	0	0	G+	G—	G+	G—
4— ,,	G+	G—	G+	G+	G+	0	0	0	G—	G+	G—	G+	G—
5— ,,	G+	G—	G+	G—	G+	0	G—	0	G+	G+	G—	G+	G—
6— Ps. rhiz	HR+	HR—	HR+	HR—	HR+	0	0	0	0	HR—	0	HR+	HR—
7— ,,	HR+	HR—	HR+	HR—	HR+	0	0	0	0	HR—	0	HR+	HR—
8— ,,	HR+	HR—	HR+	HR—	HR—	0	0	0	HR—	HR—	0	HR+	HR—
9— ,,	HR+	HR+	HR+	HR+	HR+	0	HR—	0	0	HR+	0	HR+	HR—
10— ,,	HR—	0	0	HR—	HR—	0	0	0	0	HR—	0	HR—	HR—
11— ,,	HR+	HR+	HR+	HR+	HR+	0	0	0	HR—	HR+	HR—	HR+	HR—
12— ,,	HR+	HR+	HR+	HR+	HR+	0	0	0	0	HR+	HR—	HR+	HR—
13— ,,	HR+	HR+	HR+	HR+	HR+	0	0	0	HR—	HR+	HR—	HR+	HR+
14— ,,	HR+	HR+	HR+	HR+	HR+	0	HR—	0	HR—	HR+	HR+	HR+	HR+
15— ,,	HR+						HR—	0	HR—		HR—	HR+	HR+
16— ,,	HR+												HR+
17— ,,	HR+												
18— B. radio.	0	0	0	0	0	0	0	0	0	0	0	0	0
19— ,,	0	0	0	0	0	0	0	0	0	0	0	0	0
Ck.	0	0	0	0	0	0	0	0	0	0	0	0	0

Response from inoculations is indicated as follows:
  G = Gall
  HR = Hairyroot
  + = Over 50 per cent infection
  — = Under 50 per cent infection
  0 = No infection

moderately pathogenic, culture No. 10 giving no reaction. On the other hand, *Ps. rhizogenes* isolated originally from Spiraea was highly pathogenic, typical hairyroot resulting in each case. Hairyroot formed on *Spiraea vanhouttei* is similar to that on peach seedlings as shown in Plate VI-BB. Inoculations on honeysuckle and snowberry showed that all cultures of *Ps. tumefaciens* and *Ps. rhizogenes* were pathogenic on these hosts. The pathogenicity of the different cultures of *Ps. rhizogenes* from apple varied somewhat, while those from Spiraea were quite constant in their pathogenicity. This shows that these ornamentals are susceptible to infection by *Ps. rhizogenes,* although some of the isolation trials were negative with hairyroot found occurring naturally on these hosts.

A series of nine different one-year-old seedlings from deciduous trees was inoculated with the cultures. The results obtained were quite variable. Table 11 shows that all trials on elm and ash seedlings were negative. Inoculations on locust, mulberry, and Caragana seedlings were more or less successful, although only a moderate amount of infection developed in these plants. Cultures 5, 9, 14 and 15 gave response on locust; cultures 4, 5, 9, 12, 14 and 15 on mulberry; and cultures 1, 2, 3, 4, 5, 11, 12, 13, 14 and 15 on Caragana. More positive results were obtained from inoculations on apple, peach, Russian olive, and Cotoneaster seedlings. All cultures of *Ps. rhizogenes* were highly pathogenic on apple seedlings except cultures 8 and 10 which were moderately so. Plate I-A shows form "A" hairyroot on apple seedlings. The response on peach seedlings was constant for *Ps. tumefaciens,* variable for *Ps. rhizogenes* from apple, and constant for *Ps. rhizogenes* from Spiraea. Plate VI-BB shows typical hairyroot on peach seedlings. Russian olive seedlings were susceptible to infection. All the cultures except *B. radiobacter* induced typical symptoms in Cotoneaster seedlings. Isolations were made from the hairyroot induced on each host. The cultures of *Ps. rhizogenes* obtained from these isolation trials proved to be pathogenic when inoculated into sugar beet.

Pseudomonas rhizogenes usually produced a distinct reaction upon a host in four weeks, but the time required for the symptoms to appear varied on the different hosts. From observations, the age and condition of the host were factors influencing its susceptibility. Inoculations on young, rapidly growing sugar beets which have a crown about one-fourth inch in diameter, usually show hairyroot in 14 days. On older beets, a 21 day period is more common. As a result of inoculation with *Ps. rhizogenes,* small rootlets appear on the stem of Dwarf Stone tomato in 21 days, as is also the case in inoculations on Bryophyllum. Usually 28 days were required for inoculations on Paris daisy to show the same symptoms. Inoculations on Wealthy apple produced small soft swellings in 14 days, while Form "A" hairyroot developed in about 30 days. Thirty days were required for the appearance of symptoms on peach seedlings.

SYMPTOMS INDUCED ON APPLE TREES

Examination of many apple trees in a number of nurseries had indicated that several forms of hairyroot could be found. The three forms treated in this paper as A, B, and C were considered to be induced by *Pseudomonas rhizogenes.*

In order to determine definitely the hairyroot symptoms induced in apples by *Ps. rhizogenes,* a series of 500 Wealthy apple trees was inoculated with pure cultures of *Ps. rhizogenes.* Two hundred of the trees were inocu-

lated in July, 1929, and the remainder in June, 1930. These trees were observed at regular intervals throughout the summer of 1930 and it was found that *Ps. rhizogenes* induced three somewhat distinct forms of hairyroot which have been described in an earlier part of this paper as "A", "B", and "C". Doubtless age and environment are the chief contributing factors in initiating these three classes.

In connection with the study of the forms of hairyroot produced on apple trees, one series was measured to determine the possible injurious effects of hairyroot. Iakovleff (3) reported that although the first season's growth of infected grafts was retarded, the second season of growth was as good as the controls and in some cases even outstripped the latter.

After examination of the trees to determine if the diseases were present, preliminary measurements were made on June 20, 1930 and final measurements on October 20, 1930. The results of this study are given in table 12. From these data it is shown that the trees inoculated with *Ps. rhizogenes* grew as much in caliper and height as did the normal trees. In fact there was no difference to be noticed between them in the experimental plots. In the case of the trees inoculated with *Ps. tumefaciens,* the data show that only about one-third as much growth in height and one-half as much in caliper occurred as on normal trees. The trees inoculated with Ps. tumefaciens could easily be recognized when growing in the experimental plots because of their stunted size and lack of vigor. The trees in this experiment were dug on October 25, 1930, and examined. The normal trees were free from hairyroot and crowngall. The trees inoculated with *Ps. tumefaciens* had typical soft galls from one and one-half to three inches in diameter with no roots coming from the gall tissue. The trees inoculated with *Ps. rhizogenes* showed form "B" hairyroot in every case.

TABLE 12.	*The effect of Pseudomonas rhizogenes and Ps. tumefaciens on the growth in height and caliper of Wealthy apple trees at the experimental plots, Ames, Iowa*

Treatment	No. trees	Increase					
		Height in inches			Caliper in 1/16 inches		
		Least	Most	Average	Least	Most	Average
Normal	60	14	23	17.25	2	4	3.03
Inoculated with Ps. tumefaciens	30	0	14	7.5	0	3	1.5
Ps. rhizogenes	32	13	29	17.07	2	5	3.07

Note:	First measurements — June 20, 1930
	Final measurements — Oct. 20, 1930
	Inoculations — July 30, 1929

THE RESPONSE OF PSEUDOMONAS RHIZOGENES TO CERTAIN MORPHOLOGICAL AND PHYSIOLOGICAL TESTS

The pathogenicity of the various cultures of *Ps. rhizogenes* having been established, as recorded in the preceding chapters, it seemed desirable to

study their carbon metabolism, flagellation, thermal death point, reaction on certain special media, and the accumulation of metabolic products.

METHOD OF PURIFICATION

Each culture, except numbers 16 and 17, was purified twice by the dilution plate method and its pathogenicity established.

Cultures 16 and 17 were the result of single cell isolation. The isolation technique was essentially that given by Wright, Hendrickson, and Riker (23). Isolations were made with the Chamber's micro-manipulator and because of limited time, trials were made from only one culture, *Ps. rhizogenes* No. 9. Two single cell cultures were obtained from this mother culture and were given numbers 16 and 17. The response of these two cultures when inoculated into different hosts has been given. In making the following studies, two series of three tubes each were used to obtain the data. The second series was always inoculated with the third subtransfer from the culture that was used for the first series.

CARBON METABOLISM

One of the principal means of distinguishing *Ps. tumefaciens* from *Ps. rhizogenes* has been their reaction on media containing various carbohydrates as sources of carbon. The cultures of *Ps. rhizogenes* isolated from apple and Spiraea were grown on eleven different carbohydrates and their reactions studied.

The medium consisted of a one per cent peptone broth to which the desired carbohydrate was added. In all cases 10 grams of the carbohydrate was used per liter of peptone broth. For the detection of acidity or alkalinity caused by growth of the organisms, a double indicator system was used; brom cresol purple, pH 5.4 to 6.8 and cresol red, pH 7.2 to 8.8. These indicators were made up in one per cent alcoholic solutions and one cubic centimeter of each was added to each liter of medium. The formation of a yellow color in the medium is caused by acidity, while a purple color indicates alkalinity. When sterilized, media containing galactose, arabinose, xylose or levulose became more acid. To test for gas production from growth on these 11 compounds, a small test tube 0.5 cm. x 5.0 cm. was inverted within the larger tube of medium. In all cases good growth occurred in the larger tube, but no gas was formed and no growth was observed within the small inverted tubes. The reaction obtained for each culture when grown on the 11 different carbohydrate media is shown in table 13. These results indicate that cultures of *Ps. rhizogenes* differ from those of *Ps. tumefaciens* by an acid reaction when grown in broth containing lactose, maltose, galactose, xylose, arabinose and levulose. *Pseudomonas tumefaciens* showed a slight acid reaction in dextrose, but *Ps. rhizogenes* developed a greater acidity. In the case of mannitol, sucrose, and raffinose no difference was found between the reactions of the two organisms. With salicin, however, more acid is produced by *Ps. tumefaciens* than by *Ps. rhizogenes*. *Bacillus radiobacter* reacted the same as *Pseudomonas tumefaciens* in all carbohydrates except arabinose where it produced a slight acidity. It would seem from this study that *Ps. rhizogenes* from apple and Spiraea are practically identical in their carbon metabolism and that they can be distinguished from *Ps. tumefaciens* by the acid reaction produced in certain carbohydrate media. These results are in general agreement with the results of Riker et al. (16).

TABLE 13. *Reaction of five cultures of Ps. tumefaciens, 12 cultures Ps. rhizogenes and two cultures of Bacillus radiobacter when grown on 11 different carbohydrate media*

Culture	Reaction on media containing											
	Dextrose	Lactose	Maltose	Mannitol	Salicin	Sucrose	Galactose	Xylose	Raffinose	Arabinose	Levulose
Initial pH	6.7	6.8	6.8	6.9	6.7	7.0	6.3	5.6	6.9	5.8	6.1
1— Ps. tum.	s+*	s—	0	s—	+	0	s—	s—	s—	s—	s—
2— ,,	s+	s—	0	s—	+	0	s—	s—	s—	s—	s—
3— ,,	s+	s—	s—	s—	+	0	s—	s—	s—	s—	s—
4— ,,	s+	s—	s—	s—	+	0	s—	s—	s—	s—	s—
5— ,,	s+	s+	0	s—	+	0	s—	s—	s—	s—	s—
6— Ps. rhiz.	+	s+	s+	s—	s+	0	+	+	s—	+	+
7— ,,	+	s+	+	s—	s+	0	+	+	s—	+	+
8— ,,	+	s+	s+	s—	s+	0	+	+	s—	+	+
9— ,,	+	s+	s+	s—	s+	0	+	+	s—	+	+
10— ,,	+	s+	s+	s—	s+	0	+	+	s—	+	+
11— ,,	+	s+	s+	s—	s+	0	+	+	s—	+	+
12— ,,	+	s+	+	s—	s+	0	+	+	s—	+	+
13— ,,	+	s+	+	s—	s+	0	+	+	s—	+	+
14— ,,	+	s+	+	s—	s+	0	+	+	s—	+	+
15— ,,	+	s+	s+	s—	s+	0	+	+	s—	+	+
16— ,,	+	s+	s+	s—	s+	0	+	+	s—	+	+
17— ,,	+	s+	s—	s—	+	0	+	+	s—	+	+
18— B. radio.	s+	s—	s—	s—	+	s+	s—	s—	s—	s+	s—
19— ,,	0	s—	s—	s—		0	s—	s—	s—	s+	s—

* Change in reaction due to growth of organisms is indicated as follows:
+ = Acid change from initial
— = Alkaline change from initial
s = Slight
0 = No change from initial

FLAGELLATION

In the classification of bacteria, the flagellation of the organism is of first importance. Smith, Brown and Townsend (22), Muncie and Suit (9), and others have shown that *Ps. tumefaciens* is a single polar organism usually with one flagellum. Recently Riker et al. (16) have obtained variable results as to its motility. *Pseudomonas rhizogenes* is reported by Riker et al. (16) to be single polar with usually one flagellum. They also state that *Bacillus radiobacter* is single polar, while Muncie and Suit (9), Löhnis and Hansen (5), and others have shown that this organism is peritrichic in its flagellation. In order to determine, if possible, the facts that might cause a difference in results obtained and to determine the flagellation of the cultures of *Ps. rhizogenes* from Spiraea, a study was made of the effect of the age of the culture on the flagellation of the organism.

As in other bacteriological work two series were run, while a special technique adapted from that of Kulp (4) was used. Microscope slides to be used for streaks were cleaned as follows: 48 hours in 25 per cent potassium hydroxide and then 48 hours in sulfuric acid-potassium bichromate cleaning solution. The slides were then washed well in tap water, and then in distilled water. They were next put into 95 per cent alcohol for one hour and then transferred to a solution of 50 per cent ether and 50 per cent absolute alcohol. They were taken from this solution, wiped with a clean white cloth, and kept in sealed clean glass jars. Throughout the cleaning process the slides were handled only with tweezers.

Cultures to be used for flagella staining were prepared in the following manner. Agar slants containing one or two cubic centimeters of water of condensation and sineresis were inoculated with the desired cultures and after growing for 24 hours were transferred to a second agar slant with water of condensation. After another 24 hours had elapsed, the water of condensation in the second transfer was poured into a tube of five cubic centimeters of sterile water. At certain intervals streaks were made from these water suspensions. A four millimeter loop was flattened on the bottom. To make the streak, the loop was dipped into only the top one-half centimeter of the water blank and then pushed across the cleaned slide which previously had been flamed. When the loop was pulled across the slide, the wire was necessarily also pulled over all of the streak made on the slide. This has a tendency to cause a breaking off of the flagella, which was not so evident when the loop was pushed.

After the streaks had dried they were stained for one and one-half minutes in Casares-Gil mordant diluted one to two with distilled water. They were then rinsed in running water and stained for five minutes with carbol fuchsin after which they were rinsed again. Examination was made in the usual manner using an oil immersion objective and a 15X ocular. A study of the flagellation of the organisms was made at certain intervals from the time of putting the cultures into the water blanks. The results showed that the flagellation of all cultures except *B. radiobacter* was doubtful when three hours old. Typical flagellation was obtained with all cultures when six and twelve hours old. After 24 hours the flagellation of *Ps. tumefaciens* was doubtful, but *Ps. rhizogenes* and *B. radiobacter* were still typical in their flagellation. After 48 and 72 hours no flagella could be found on *Ps. tumefaciens*. *Bacillus radiobacter* was doubtful after 48 hours and no flagella were found after 72 hours. The flagellation of *Ps. rhizogenes* was typical up to and including 72 hours old. A distinct difference was

noted between the polar flagellation of *Ps. tumefaciens* and *Ps. rhizogenes*. *Pseudomonas tumefaciens* is typically single polar with one flagellum although two and occasionally three were found, whereas *Ps. rhizogenes* is typically single polar with two to four flagella and occasionally only one. *Bacillus radiobacter* showed typical peritrichous flagellation.

THERMAL DEATH POINT

The data presented by Muncie and Suit (9) indicated a possible difference in the thermal death points of *Ps. tumefaciens* and *Ps. rhizogenes*. If this difference exists it should be possible to remove all doubt as to the identity of *Ps. tumefaciens* and *Ps. rhizogenes* by exposing them to a minmum temperature that will kill one of the organisms. To check this possible difference in thermal death points, a study was made of the 19 cultures. Dunham solution at a pH of 6.8 was the standard medium for this work. Two series of the organisms were exposed by the use of one cc. of 24-hour cultures in ampoules, while two other series were exposed as 24-hour cultures in test tubes five-eights of an inch in diameter and containing 10 cc. of broth. Exposures were made for ten minutes and at temperatures of 50, 52, 54, and 56°C. After treatment, transfers from each ampoule and tube were made into two tubes of broth. All cultures grew readily after exposure at 50°C. After exposures at 52, 54, and 56°C. no growth was obtained from any of the cultures. This indicates that the thermal death point of *Ps. tumefaciens, Ps. rhizogenes* and *B. radiobacter*, growing in Dunham solution at a pH of 6.8, was 52°C. when exposed for 10 minutes.

REACTION ON DIFFERENTIAL MEDIA

Since *Ps. rhizogenes* and *Ps. tumefaciens* differ in some of their cultural characteristics, it was quite possible that a medium could be found which would serve to differentiate these two organisms. Riker et al. (16) have obtained results using a glycerophosphate medium containing mannitol. They reported that in this medium *Ps. tumefaciens* and *B. radiobacter* gave abundant growth while *Ps. rhizogenes* showed none or only a trace. Also Berthelot (1) has devised a medium especially for the cultivation of *Ps. tumefaciens*.

The agar medium devised by Patel (10) for the isolation of *Ps. tumefaciens* is also excellent for *Ps. rhizogenes*. Since the difference in acid production by these two organisms is quite marked, it was thought that this fact might serve as a means of differentiation. Consequently Patel's medium was modified by adding one cc. of a 1-1000 alcoholic solution of brom cresol purple and one cc. of a like solution of cresol red to each liter. Variable results were obtained by using this medium for isolation and differentiation. *Pseudomonas tumefaciens* colonies usually remained translucent as on the original medium. *Pseudomonas rhizogenes,* being a strong acid producer, showed yellow colonies. That is, the colonies of this organisms absorbed the double indicator to such an extent that they became yellow. However, when a mixture of *Ps. tumefaciens* and *Ps. rhizogenes* was grown on this medium, all of the colonies became yellow. Isolation trials from crowngall showed translucent colonies while trials from the three types of hairyroot showed yellow colonies with a few white ones when this special medium was used. An inoculation experiment with cultures isolated from the same hairyroot specimens, using both Patel's medium and the modified

TABLE 14. *Reactions of Ps. tumefaciens, Ps. rhizogenes, and Bacillus radiobacter on differential media at 28°C.*

Culture	Glycerophosphate medium Time	Growth	Berthelot's medium Time	Growth	Dunham solution Time	Growth	NH_4 test	+ Dextrose Time	Reaction	+ Salicin Time	Reaction
1— Ps. tum.	10 da.	4*	3 da.	4	3 da.	4	G	4 da.	S+	4 da.	S+
2— ,, ,,	,,	4	,,	4	,,	4	G	,,	S+	,,	S+
3— ,,	,,	4	,,	4	,,	4	G	,,	S+	,,	S+
4— ,,	,,	4	,,	4	,,	4	G	,,	S+	,,	S+
5— ,,	,,	4	,,	4	,,	4	G	,,	+	,,	+
6— Ps. rhiz.	,,	1	,,	2	,,	2	S	,,	+	,,	+
7— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	+
8— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	+
9— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	+
10— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
11— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
12— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
13— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
14— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
15— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
16— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	0
17— ,,	,,	1	,,	2	,,	2	S	,,	+	,,	+
18— B. radio.	,,	1	,,	4	,,	4	G	,,	S+	,,	S+
19— ,,	,,	1	,,	4	,,	4	G	,,	S+	,,	S+

* Growth and reaction of the organisms is indicated as follows:
1 = Slight clouding
2 = Moderate clouding
3 = Good clouding
4 = Pellicle formed
+ = Acid
S = Slight test
G = Good test

medium, was tried. Translucent, raised, whitish colonies were selected from isolation plates made with the original medium. Thirty-five per cent of these colonies proved to be *Ps. rhizogenes* when inoculated into sugar beet. The yellowish, shining, raised colonies selected from the plates with modified medium were 67 per cent *Ps. rhizogenes* when inoculated into sugar beet. While this medium is not perfect, it does increase the number of colonies of *Ps. rhizogenes* selected. All incubation of isolation plates was at 28°C. and the colonies were selected at the end of three days.

In table 14 are shown some of the typical reactions of *Ps. rhizogenes* and *Ps. tumefaciens* when grown on the different media. A difference in the growth of *Ps. tumefaciens* and *Ps. rhizogenes* in glycerophosphate medium was not evident until after 10 days. At this time a pellicle had been formed by the cultures of *Ps. tumefaciens* and only a slight clouding of the medium by *Ps. rhizogenes*. This same differentiation was obtained in three days on Berthelot's medium and on ordinary Dunham solution. It was observed that this difference existed when using any liquid medium in which the two organisms were grown. *Pseudomonas tumefaciens* and *Ps. rhizogenes* can also be differentiated by the amount of ammonia produced. On modified Patel's medium a differentiation can also be obtained in three to four days. When salicin was added as a source of carbon instead of dextrose, the cultures of *Ps. rhizogenes* obtained from Spiraea showed no change of reaction in four days, while those from apple showed a slight acidity. This was the only instance in which *Ps. rhizogenes* from Spiraea produced a different reaction from the same organism isolated from apple. These results would indicate that a good bacteriological test to differentiate *Ps. tumefaciens* from *Ps. rhizogenes* would be by their distinct manner and rate of growth in liquid media.

EFFECT OF AGE OF CULTURE OF VIRULENCE OF PS. RHIZOGENES

At various times during the work with *Ps. rhizogenes* difficulty developed in making transfers of stock cultures. This suggested that the accumulation of metabolic products might have an inhibitory effect or that a different form of the organism might be obtained from an old culture. In order to study the effect of age of the culture, *Ps. tumefaciens* and *Ps. rhizogenes* were transferred to four series of peptone-dextrose agar slants to which had been added two grams of dipotassium phosphate per liter. After two days growth the cultures were kept in the refrigerator at 10°C. Inoculations were made into ten sugar beets every two months, the inoculations being made from the original culture that was transferred at the beginning of the experiment. The results of this study are shown in table 15 and show that cultures of *Ps. rhizogenes* were still virulent after two months without transfer. After four months the virulence was variable, and after six months the cultures were apparently dead as they would not produce hairyroot and would not grow on fresh agar slants. Twenty trials were made in transferring each six-months-old culture of *Ps. rhizogenes* but all were negative. It is evident that certain metabolic or staling products were formed which killed the organism. The cultures of *Ps. tumefaciens* remained viable throughout the six months' period, while no evidence was found which would indicate a change of *Ps. rhizogenes* to *Ps. tumefaciens* with the increased age of the culture.

TABLE 15.   *Pathogenicity of Ps. tumefaciens and Ps. rhizogenes on young sugar beets after two, four and six months from the time of transfer*

Culture	Number sugar beets infected with culture				Successful transfer from six month old culture
	Two days old	Two months old	Four months old	Six months old	
1— *Ps. tum.*	10	10	10	10	+
2— ,, ,,	10	10	10	10	+
3— ,, ,,	10	10	10	10	+
4— ,, ,,	10	10	10	10	+
5— ,, ,,	10	10	10	10	+
6— *Ps. rhiz.*	10	10	3	0	—
7— ,, ,,	10	10	2	0	—
8— ,, ,,	10	10	1	0	—
9— ,, ,,	10	10	5	0	—
10— ,, ,,	10	10	8	0	—
11— ,, ,,	10	10	6	0	—
12— ,, ,,	10	10	7	0	—
13— ,, ,,	10	10	5	0	—
14— ,, ,,	10	10	8	0	—
15— ,, ,,	10	10	10	0	—
Ck.	0	0	0	0	

CONTROL OF HAIRYROOT INDUCED BY PS. RHIZOGENES BY MODIFICATION OF GRAFTING PRACTICES

Since the greater percentage of infection by *Ps. rhizogenes* occurs at the union of piece-root grafted apple trees, it was thought that this disease might be controlled by certain modifications in grafting practice, which were beneficial in the control of callus knot.   Previous to 1926 the common practice of piece-root grafting was the tongue, or whip graft, wound with waxed string.   Since that time, several modifications in grafting practice have been used, which reduce the percentage of malformations at the union. Melhus, Muncie and Fisk (7) recommended the wedge, or cleft graft, as being desirable.   Riker, Keitt and Banfield (15) have shown that beneficial results can be obtained by using a nurseryman's tape as a wrapper for grafts.   Maney (6) suggested the use of the double tongue graft as a means for control of overgrowths.

A study was made of these three methods of control as they apply to infection by *Ps. rhizogenes*.   Wealthy, being the variety most susceptible to infection by *Ps. rhizogenes*, was chosen for experimentation.   Other varieties were also included for comparison.   Results of trials on 3,000 one-year trees were obtained from the experimental plots at Ames, Iowa, while the other results were obtained from experimental plots at nurseries in the states indicated.   The data obtained in this study are presented in table 16.   Of the three types of grafts studied, these data show that irrespective of the type of wrapper employed, the wedge graft has a lower percentage of hairyroot than the other two types.   A close examination of the three different types of grafts shows that the wedge graft has the least cut surface exposed to contact with the soil while the double tongue has the greatest exposed cut surface.   Since *Ps. rhizogenes* is a wound parasite, the double tongue graft afforded more chances for infection than the other two types.

TABLE 16. *Results obtained from a study of three types of grafts and two kinds of wrappers as they influenced the percentage of hairy-root.*

State	Variety	Age	Wrapper	Wedge grafts		Tongue grafts		Double tongue grafts	
				No. observed	Percentage hairyroot	No. observed	Percentage hairyroot	No. observed	Percentage hairyroot
Iowa	Wealthy	1 yr.	Tape	311	3.8	364	3.8	322	3.7
,,	,,	,,	String	412	7.5	393	5.1	844	17.1
,,	,,	2 yrs.	Tape	472	0.2	437	0.6		
,,	,,	,,	String	309	1.9	414	6.2		
Kansas	,,	,,	Tape	490	9.7	480	14.3		
,,	,,	,,	String	480	24.7	486	40.7		
,,	Yellow Transparent	,,	Tape	507	6.5	481	11.8		
,,	,,	,,	String	496	8.4	470	19.7		
Nebraska	,,	,,	Tape	166	2.4	207	1.9		
,,	,,	,,	String	199	0	192	5.7		
,,	Wealthy	,,	Tape	363	0.8	187	3.2		
,,	,,	,,	String	327	0.9	189	6.3		
,,	Whitney	,,	Tape	196	0	157	3.1		
,,	,,	,,	String	196	1.0	190	10.0		
Total	,,		Tape	2505	4.1	2540	6.2	322	3.7
,,	,,		String	2419	8.3	2334	15.3	344	17.1

A further examination of table 16 shows that when the type of graft is disregarded, the use of nurseryman's tape as a wrapper is superior to the use of waxed string for controlling *Ps. rhizogenes* infection. The advantage of tape is, that all cut surfaces are covered, while with the string wrap the cut surfaces are exposed. Siegler (21) showed that after callus was formed, the graft was not susceptible to infection. However, it is possible that in the nursery method of cultivation, some of the grafts are disturbed with enough force to break the callus and thus form another chance of infection in the case of the string wrapped grafts. From the results obtained, the most effective control indicated for *Ps. rhizogenes* is the wedge graft wrapped with nurseryman's tape.

DISCUSSION

The first isolation of an organism from hairyroot was reported by Smith, Brown and Townsend (22). They showed that this organism was closely related to *Ps. tumefaciens* and thought that, for the present, the hairyroot organism should be called a strain of *Ps. tumefaciens*. They stated, however, that further work on this problem might show the hairy-root organism to be a distinct species. Until 1928, hairyroot was considered to be caused by *Ps. tumefaciens*. In 1928 Riker, Banfield, Wright and Keitt (14) suggested that there might be a species difference between *Ps. tumefaciens* and the hairyroot organism. Siegler (17), however, maintained that this organism isolated from woolly knot on apple resembled *Ps. tumefaciens* on agar and should be called the apple strain of the crowngall organism. In Siegler's further work (18, 19) he still maintained that this hairyroot organism was not a distinct species, without giving any bacteriological evidence to substantiate his opinion. Brown (2) also showed that when culture of *Ps. tumefaciens* were inoculated into the node or growing point certain small roots and rootlets would appear under certain conditions. At this time Muncie and Suit (9) showed that there was evidence of two types of hairyroot organisms, but they did not suggest setting out of a separate species at that time. In 1930 Riker et al. (16) presented additional bacteriological studies and named the hairyroot organism *Phytomonas rhizogenes*. It is also worthy of mention that illustrations given by Siegler (17, 18, 19), Muncie and Suit (9), and Riker et al. (16) for naturally occurring and artificially induced hairyroot are practically identical. Muncie and Suit (9) and Riker et al. (16) stated that *Ps. rhizogenes* resembled *Ps. tumefaciens* in agar culture. It is possible, therefore, that had Siegler (17, 19) made bacteriological studies of the organisms he used, he would have found differences.

It is true that there are many points of similarity between the bacteriological reaction of *Ps. tumefaciens* and *Ps. rhizogenes*. The differences are, however, of such a fundamental nature that one is justified in considering it a new species. Data presented in this paper strengthen the evidence for calling the hairyroot organisms a distinct species, *Ps. rhizogenes*. The hairyroot pathogen has been isolated from naturally occurring hairyroot on *Spiraea vanhouttei* and *Spiraea prunifolia* as well as on apple. The *Ps. rhizogenes* from Spiraea was more virulent when artificially inoculated into three kinds of ornamental shrubs and seven kinds of one-year-old seedlings than was *Ps. rhizogenes* from apple. However, these cultures of *Ps. rhizogenes* were identical in their bacteriological reactions. Further evidence of a species difference is indicated by the manner of growth in a liquid medium.

Pseudomonas tumefaciens forms a pellicle in three days while *Ps. rhizogenes* produces only a slight to moderate clouding and as growth proceeds the organisms settle to the bottom of the tube. This difference in growth would indicate a possible difference in the oxidation-reduction reactions of the two organisms. Another difference between the organisms is the accumulation of staling products. *Pseudomonas rhizogenes* was completely killed when kept on the same agar slant for six months, while *Ps. tumefaciens* was not noticeably affected.

Not only are there bacteriological differences, but also symptomatic differences between *Ps. tumefaciens* and *Ps. rhizogenes*. Three cultures of *Ps. tumefaciens* isolated from crowngall on apple showed no stimulation of roots, but induced typical galls when inoculated into the internode of all the hosts used. On the other hand, the cultures of *Ps. rhizogenes* induced typical hairyroot, but no galls on the internode of these plants. These differences, as well as those reported by Riker et al. (16) justify the setting out of a new species in the case of the hairyroot organism.

The specific differences found between *Ps. rhizogenes* and *Ps. tumefaciens* are:

Characteristic	Ps. rhizogenes	Ps. tumefaciens
Staling products	Cultures die in six months	No evidence of such products
Carbon metabolism		
Lactose	acid	Slight alkaline
Maltose	,,	No change
Galactose	,,	Slight alkaline
Xylose	,,	,, ,,
Arabinose	,,	,, ,,
Levulose	,,	,, ,,
Flagellation	Single polar (1-4 flagella)	Single polar (usually one flagellum)
Growth in liquid medium	Moderate clouding and settling	Pellicle
Reaction on host	Hairyroot	Crowngall

The harmful nature of hairyroot has been quite generally accepted because of its previous association with crowngall. However, it may well be that *Ps. rhizogenes* is not harmful and might even be beneficial. As was shown previously, two-year Wealthy apple trees having form "B" hairyroot at the crown, grew as much in height and caliper during an extremely dry season as did the normal trees. On the other hand, the trees inoculated with *Ps. tumefaciens* grew only one-third as much as the others. Isolation from form "A" and "B" hairyroot showed that it was more difficult to obtain *Ps. rhizogenes* from form "B". It was also shown that *Ps. rhizogenes* produced staling products which resulted in its death in six months when on an agar culture. It may be that this same phenomenon occurs in the hairyroot on apple and that after three or four years *Ps. rhizogenes* will have died out leaving only the increased number of roots on the host.

Riker et al. (16) have reported that a culture was occasionally obtained from hairyroot that appeared to be a mixture of *Ps. rhizogenes* and *Ps. tumefaciens*. In connection with the inoculation and bacteriological studies herein reported, cultures were used that had been obtained by two different methods, namely, the dilution plate method, and single bacteria isolated by

the aid of a micromanipulator. Of the 19 cultures used, two of *Ps. rhizogenes* were single cell isolations while the rest, 10 of *Ps. rhizogenes,* five of *Ps. tumefaciens* and two of *B. radiobacter* were plate purified. At no time was there any evidence obtained that indicated any difference in the purity of the cultures irrespective of the method of purification. No indication of any mixture of organisms was found in any of the cultures isolated and tested for pathogenicity; neither those of *Ps. rhizogenes* nor those of *Ps. tumefaciens.*

SUMMARY

Examination of 20 varieties of two-year and two-year cut-back apple trees in nurseries in five states showed hairyroot present on all varieties. The percentage varied from 1.7 on Delicious in Kentucky to 45.2 on Wealthy in Oklahoma. A higher percentage of hairyroot was found on trees in Kansas and Oklahoma than on those in Iowa, Kentucky and Nebraska. *Pseudomonas rhizogenes* occurred most commonly on Wealthy, Yellow Transparent, and Duchess and occasionally on Jonathan, Delicious and Stayman.

Pseudomonas rhizogenes was found to induce three forms of hairyroot on apples. Form "A" is characterized by an abundance of fleshy roots and is the symptom of the first growing season. Form "B" is commonly termed hairy or woolly knot and is one-year-old hairyroot. The reaction induced by *Ps. rhizogenes* on the aerial parts of the host shows a cluster of small rootlets that is designated as form "C" hairyroot.

A higher percentage of hairyroot occurred on those apple trees that had woolly aphid injury than on those trees free from this insect.

Where one-year-old Wealthy apple trees were inoculated with *Ps. tumefaciens* and *Ps. rhizogenes* and then grown for one season, stunting was evident in the former and not in the latter.

Hairyroot not only occurs on apple, but also on ornamental shrubs. It was found on *Spiraea vanhouttei, S. prunifolia, Lonicera tartarica,* and *Symphoricarpus racemosus.*

Pseudomonas rhizogenes was isolated from hairyroot on *Spiraea vanhouttei* and *Spiraea prunifolia,* but could not be obtained from hairyroot on *Lonicera tartarica* and *Symphoricarpus racemosus.* The causal agent was also isolated from hairyroot on apple trees grown in Iowa, Kentucky, Oklahoma, Kansas and Nebraska. *Pseudomonas rhizogenes* can easily be obtained from form "A" hairyroot, but is rather difficult to obtain from form "B".

Hairyroot was induced by *Ps. rhizogenes* on the following hosts: sugar beet (*Beta vulgaris* L.), tomato (*Lycopersicon esculentum* Mill.), Paris daisy (*Chrysanthemum frutescens* L.), *Bryophyllum calycinum* L., bean (*Phaseolus vulgaris* L.), *Coleus blumei* Benth., Wealthy apple (*Pyrus malus* L.), *Spiraea vanhouttei* Zabel, honeysuckle (*Lonicera tartarica* L.), snowberry (*Symphoricarpus racemosus* Michx.), and apple (*Pyrus malus* L.), locust (*Gleditsia triacanthos* L.), mulberry (*Morus alba* L.), peach (*Prunus persica* Sieb. & Zucc.), *Caragana arborescens* Lam., Russian olive (*Elaeagnus angustifolia* L.), and *Cotoneaster acuminata* Lindl. seedlings. Hairyroot was not induced on white ash (*Fraxinus Americana* L.) and American elm (*Ulmus Americana* L.).

When herbaceous cuttings were inoculated with *Ps. rhizogenes,* rooting was stimulated in 30 days on cuttings of Bryophyllum and Paris daisy, while no difference was noted on Coleus. Similar inoculations on hardwood

cuttings showed a stimulation of rooting of cuttings of apple seedling, Wealthy apple and *Spiraea vanhouttei.*

A study of the acidity of the host plant extract showed no relation to the amount of hairyroot induced by *Ps. rhizogenes* on those hosts. The formation of hairyroot on inoculated Wealthy apple grafts and peach seedlings under field conditions, was influenced more by the rainfall than by either the soil temperature or the season under the conditions of the summer of 1930. *Pseudomonas rhizogenes* usually induces hairyroot on a host in thirty days. The shortest time found was 14 days on young sugar beets, while on the Wealthy apple it required 30 days.

Pseudomonas tumefaciens and *Ps. rhizogenes* may be readily differentiated by their growth in liquid media. Dunham solution was as effective a differential medium as calcium glycerophosphate-mannitol medium or Berthelot's medium.

Results from the experimental plots at Ames, Iowa, and nurseries in Iowa, Kansas and Nebraska showed 4.1 per cent, 6.2 per cent and 3.7 per cent hairyroot, respectively, for wedge, tongue, and double tongue grafts wrapped with nurseryman's tape. When the grafts were wrapped with waxed string, 8.3 per cent, 15.3 per cent, and 17.1 per cent hairyroot, respectively, occurred. When the number of trees used and the effect of the types of wrapper are taken into consideration, these results indicate that the wedge graft wrapped with adhesive tape was the most effective way of reducing hairyroot on piece-root-grafted apple trees of the varieties studied.

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PLATE I

A—Hairyroot induced on two-year apple seedlings by artificial inoculation with *Ps. rhizogenes.* The fleshy condition of the roots is a distinctive feature. Inoculated on June 30, 1930, and the picture taken on November 19, 1930. A—Hairyroot induced by *Ps. rhizogenes* isolated from hairyroot on apple. B—Hairyroot induced by *Ps. rhizogenes* isolated from hairyroot on *Spiraea vanhouttei.* From experimental plots, Ames, Iowa.

B—Hairyroot induced on two-year Wealthy apple by artificial inoculation with *Ps. rhizogenes.* The pronounced swellings with fibrous and woody roots are distinctive. Inoculated on July 15, 1929. The picture was taken December 5, 1930. From experimental plots, Ames, Iowa.

Plate I

PLATE II

A—Hairyroot found occurring under natural conditions in connection with woolly
    aphid (*Ericsoma lanigera*) injury on two-year apple seedlings. It is noted
    that the hairyroot usually originates from a woolly aphid gall. From experi-
    mental plots, Ames, Iowa.

B—Hairyroot found occurring naturally on *Spiraea vanhouttei*. From a survey
    at Shenandoah, Iowa, during the fall of 1930.

Plate II
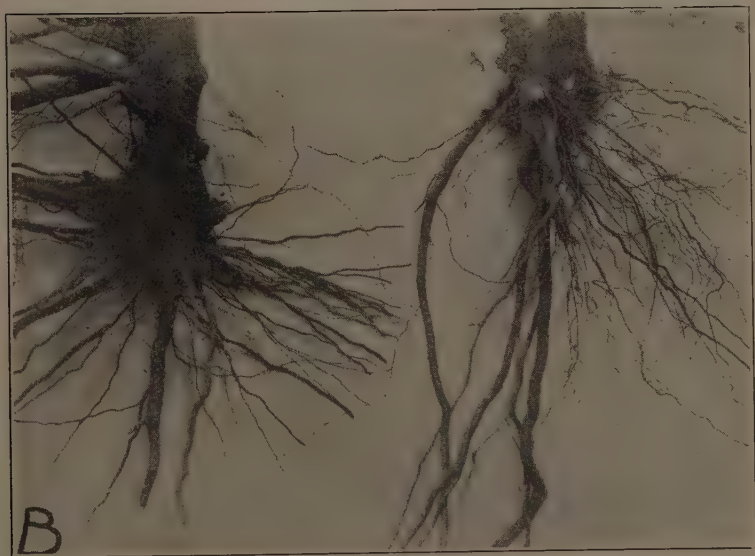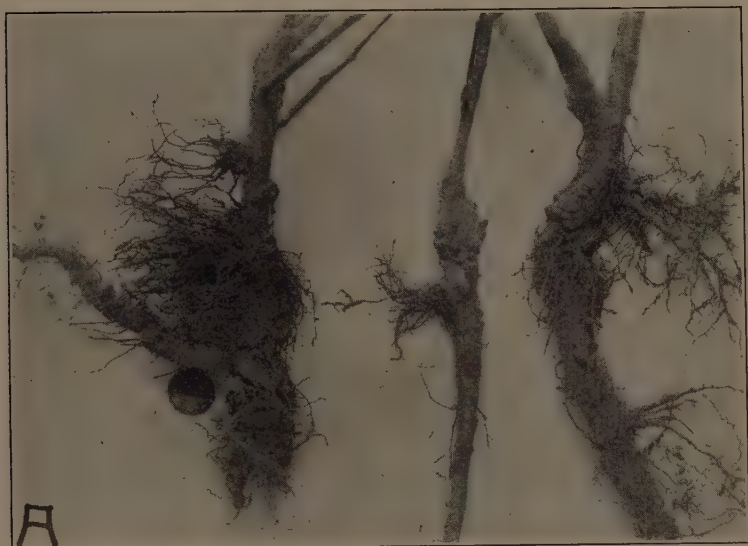
PLATE III

A—Reaction obtained by inoculation of Bryophyllum in the internodes. Inocula-
tions were made on June 20, 1930. A—Rooting on the internodes induced by
inoculation with *Ps. rhizogenes.* B—Inoculation with a sterile needle pro-
duced a wound that healed over. C—Galls induced on the internode by *Ps.
tumefaciens.*

B—Typical response induced in Paris daisy by artificial inoculation. Inocula-
tions were made on March 8, 1930, and picture taken on June 11, 1930. A—
shows the reaction from inoculation with a sterile needle. B—Small rootlets
induced at the point of inoculation with *Ps. rhizogenes.* C—Galls induced by
Ps. tumefaciens.

C—Typical response obtained by inoculation into the crown of sugar beets grown
in the greenhouse. Inoculations were made on January 28, 1930, while the
picture was taken March 25, 1930.
A—Results of inoculation with a sterile needle.
B—Gall induced by *Ps. tumefaciens.*
C—Hairyroot induced by *Ps. rhizogenes.*

Plate III
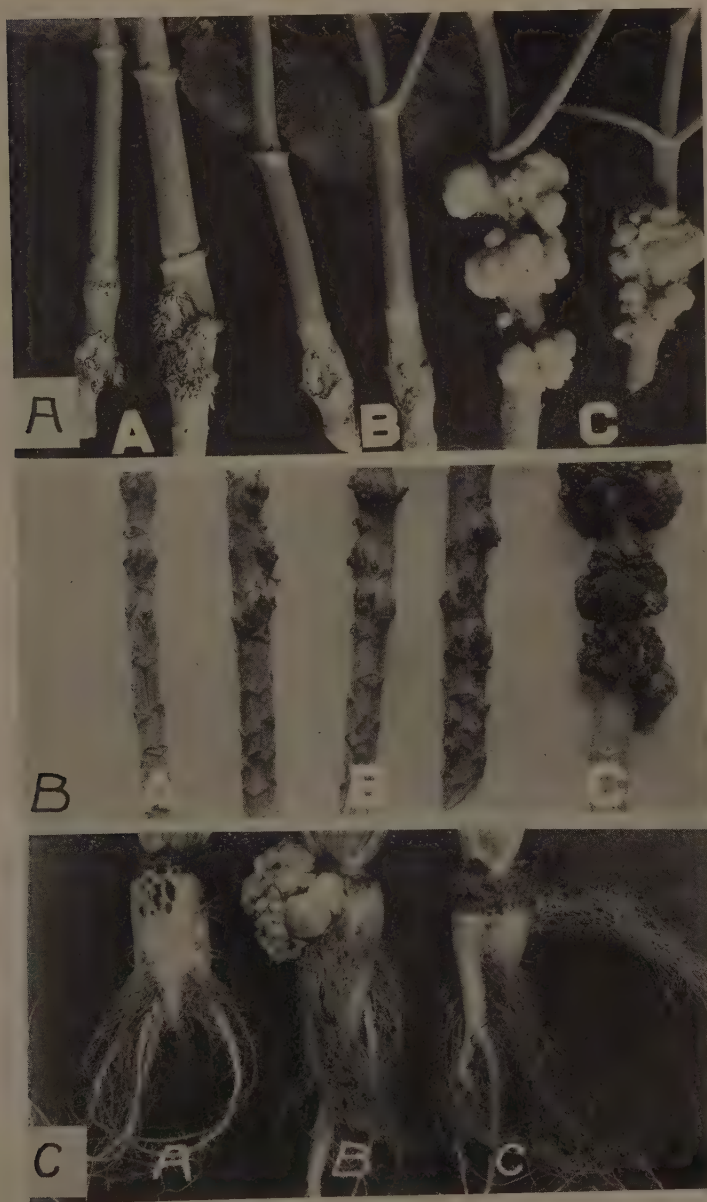
PLATE IV

A—Development of roots from form C hairyroot. Plants inoculated January 18, 1930, cuttings made and buried in sand April 5, 1930, and picture taken on May 23, 1930. A—Development of roots from point of inoculation with *Ps. rhizogenes* on the internode of Bryophyllum. B—Development of roots from form C hairyroot induced on Paris daisy by *Ps. rhizogenes*.

B—Normal rooting of cuttings inoculated with a sterile needle. Inoculations were made on January 18, 1930, cuttings made and stems buried in sand on April 5, while the picture was taken on May 23, 1930. A—Normal rooting of Bryophyllum cuttings occurring only at the base and nodes. B—Normal rooting of Paris daisy cuttings occurring only at the base.

Plate IV
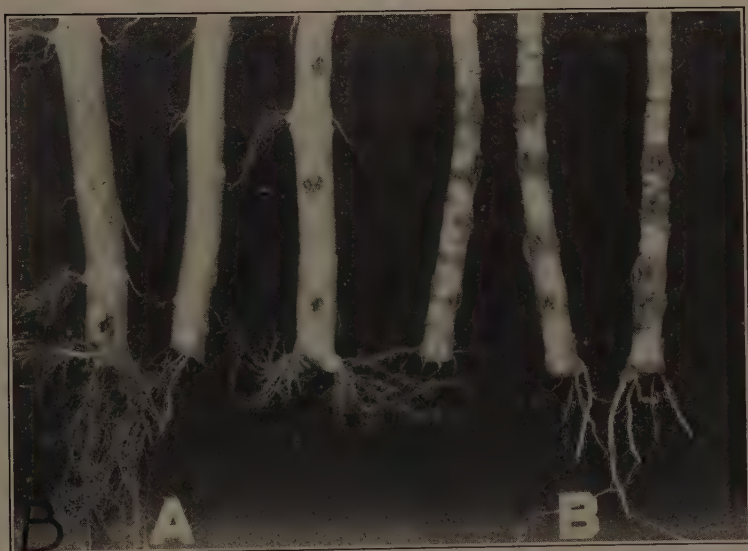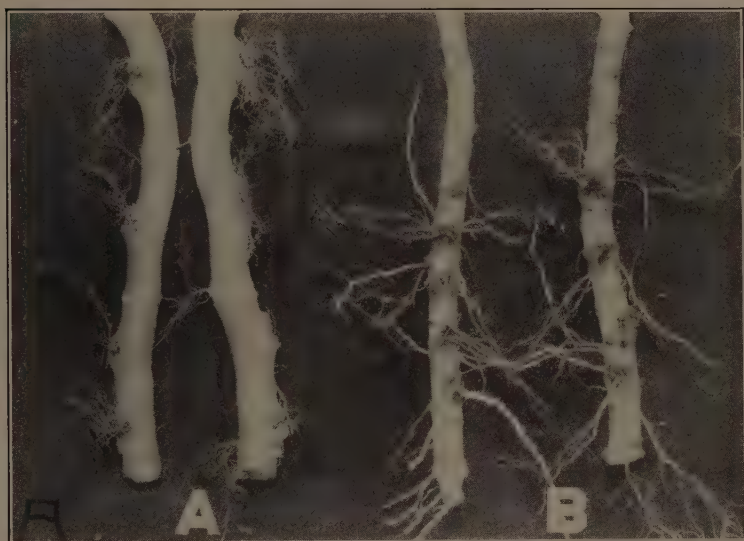
PLATE V

A—Cuttings of Bryophyllum selected at random from inoculated and check series
    25 days after the start of the experiment.   A—Root stimulation caused by
    inoculations with *Ps. rhizogenes*.   B—Normal cuttings showing only very
    small rootlets.

B—Rooted cuttings of *Spiraea vanhouttei* obtained from 100 used at the start of
    the experiment.   Inoculated on February 5, 1931, and the picture taken on
    March 27, 1931.   A—Rooted cuttings from the check series.   B—Rooted cut-
    tings from the series inoculated with *Ps. rhizogenes* from apple.   C—Rooted
    cuttings from the series inoculated with *Ps. rhizogenes* and *Spiraea vanhout-
    tei*.

Plate V
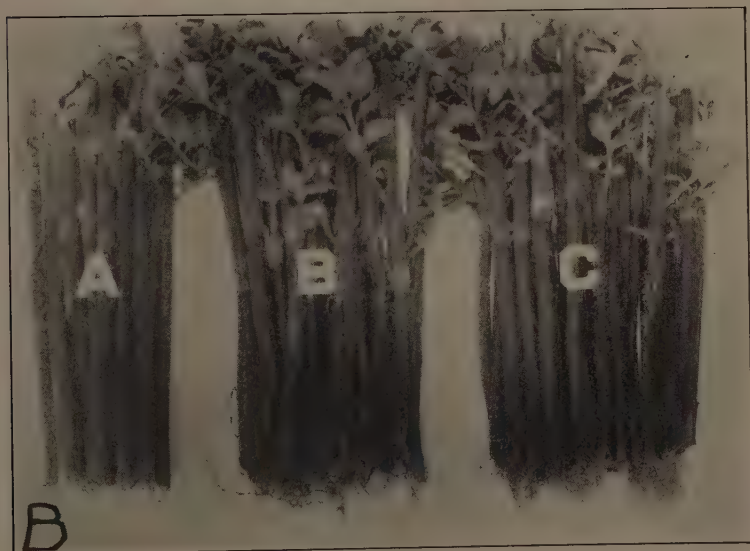
PLATE VI

A—Form C hairyroot induced on Dwarf Stone tomato by inoculation with *Ps. rhizogenes*. Inoculations were made on April 18, 1930, and the picture was taken on June 11, 1930. The typical small rootlets formed at the point of inoculation are easily visible in B while A shows two stems inoculated with a sterile needle.

B—Form A hairyroot induced by artificial inoculation with *Ps. rhizogenes*. Inoculations were made on July 1, 1930, and the picture was taken on November 19, 1930. A—Typical hairyroot induced on Wealthy scion. B—Typical hairyroot induced on peach seedling. From the Experimental plots, Ames, Iowa.

Plate VI
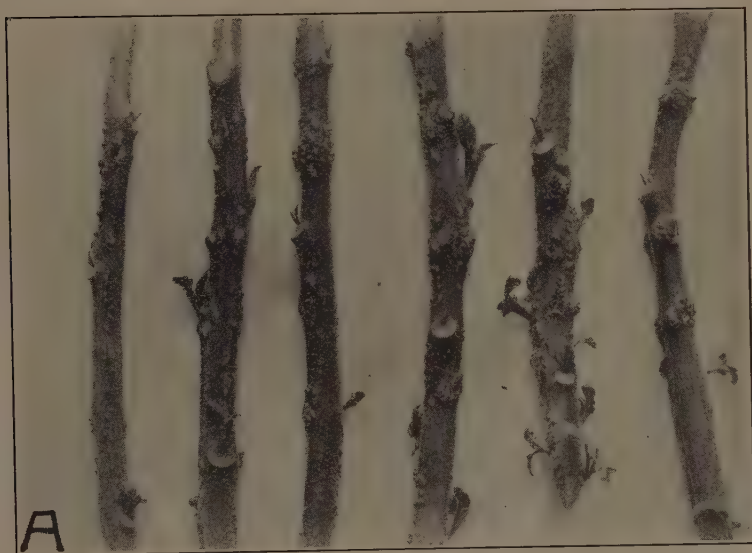
THE PHYSICAL-CHEMICAL PROPERTIES OF ALCOHOL-GASOLINE BLENDS

II.—THE INFLUENCE OF ANHYDROUS ETHYL ALCOHOL CONCENTRATION UPON WATER ABSORPTION

Leo M. Christensen, R. M. Hixon and Ellis I. Fulmer

From the Department of Chemistry, Iowa State College

n In the first paper in this series the authors (1) dealt with the influence of alcohol concentration and temperature upon the water-holding capacity of ethyl alcohol-gasoline systems. The present communication deals with the absorption of water by such blends under various atmospheric conditions.

There has been considerable discussion of this problem in the scientific and popular literature but adequate quantitative data are not available. Coutant and Mariller (2) determined the water absorption of a 15 per cent alcohol-gasoline blend under very severe conditions such as large surface contact with a very humid atmosphere, agitation of the receptacle and so forth. After 43 hours it was determined that sufficient moisture had been absorbed to raise the separation temperature to —8°C. (+17.6°F.)

Spausta (3) exposed various blends to the atmosphere for three months in flasks loosely stoppered with cotton. His data are found in columns 1, 2, and 3 in table 1. In columns 4 and 5 we have calculated the water absorbed per 100 cc. of blend and per 100 cc. of alcohol. It is evident that the water absorbed per 100 cc. of alcohol is at a definite maximum at 15 per cent, a fact in agreement with our results discussed below.

TABLE 1. *Influence of alcohol concentration upon water absorption by alcohol-gasoline blends according to Spausta* (3)

1 Alcohol in blend Wt.-pc't'g.	2 Water tolerance of 100 cc. blend Initial	3 Water tolerance of 100 cc. blend After 3 monhts	4 Water absorbed per 100 cc. blend	5 Water absorbed per 100 cc. alcohol
10.0	0.35	0.27	0.08	0.8
15.0	0.58	0.35	0.23	1.53
20.0	0.83	0.60	0.23	1.15
25.0	1.12	0.85	0.27	1.08
30.0	1.41	1.20	0.21	0.70
35.0	1.78	1.60	0.18	0.51
40.0	2.13	2.00	0.13	0.30
45.0	2.52	2.30	0.22(?)	0.49
50.0	2.90	2.80	0.10	0.20

In considering the absorption of water by alcohol blends, it is apparent that there are many phenomena involved. Water may be absorbed as a result of hygroscopicity, by condensation upon the surface as a result of the cooling caused by evaporation, or by condensation on the walls of the containing vessel due to "breathing" and temperature fluctuations. It,

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therefore, seems advisable to use the term "water absorption" instead of "hygroscopicity" in describing the experiments herein reported.

EXPERIMENTAL

Three types of data were obtained. In Series I the humidity was held at constant value, in one run at 100 per cent and in the other at 50 per cent relative humidity. In each case 50 cc. portions of the blends containing varying concentrations of alcohol, were placed in 100 cc. Erlenmeyer flasks which were fitted with 2 mm. glass vents. These flasks were placed in desiccators filled with water or with 43 per cent sulphuric acid in order to give the 100 per cent and 50 per cent humidity. The desiccators were kept alternately for 12 hrs. at $0°$ and $38°C$. The cloud points were determined at the end of 5, 10 and 15 days, using the method described in our previous paper. The water absorbed was calculated by means of the following general equation:

$$(1) \quad \log(W \times 10^2) = \log a + \log(nt° + q)$$

in which W is the cc. of water required per 100 cc. of blend at alcohol concentration a to produce turbidity at temperature t. For the gasoline employed the equation is:

$$(2) \quad \log(W \times 10^2) = 1.27 \log a + \log(0.027t° + 1.33)$$

In Series II the commercial conditions of storage were more nearly simulated. A 500 cc. portion of each blend was placed in a 1,000 cc. bottle fitted with a stopper carrying a 2 mm. bent glass vent. These were stored out of doors, and were loosely covered to prevent access of rain or other adventitius moisture.

Series III deals with data on the water absorption of 10 per cent alcohol-gasoline blends held under actual commercial storage conditions.

DISCUSSION OF RESULTS

SERIES I

The data are given in table 2 in which are recorded the cloud temperature, water absorbed per 100 cc. of blend and per 100 cc. of alcohol for each alcohol-gasoline mixture. It is evident that the water absorbed per 100 cc. of alcohol in the blend first increases and then decreases with increase in alcohol concentration. The maximum water absorption is at approximately 15 per cent alcohol for 50 per cent humidity and at 8 per cent for 100 per cent humidity. The maximum water absorption at 100 per cent humidity is about 2.1 times the maximum value at 50 per cent humidity, practically the same ratio (1.9) holding for the 10 per cent blend. It is of interest to note that the analysis of the data of Spausta in table 1 shows a maximum water absorption per 100 cc. of blend to be at 15 per cent alcohol corresponding to our results at 50 per cent humidity. The actual amount of water absorbed in three months is less than that found by us after fifteen days at 50 per cent humidity.

The procedure of alternating the temperature from $0°$ to $38°$ each twelve hours leads to higher water absorption than would take place at constant temperature because of the accentuation of the phenomenon of "breathing".

TABLE 2. *Influence of alcohol content upon water absorption by 50 cc. blend in 100 cc. E. flask equipped with 2 mm vent exposed indicated time in 50 per cent and 100 per cent saturated atmosphere at 0°C.—98°C., temperature changed twice daily. Initial water content nil and cloud point below —60°*

| Relative humidity P'c't'g. | Alcohol in Blend P'c't'g. by Vol. | Cloud point °C | | | Water absorbed | | | | | |
| | | | | | cc/100 cc. blend | | | cc/100 cc. alc. in blend | | |
		5 days	10 days	15 days	5 days	10 days	15 days	5 days	10 days	15 days
50	0	-60*	-60*	-60*	0	0		0	0	0
	1	-60	-60	-12	0	0	0.010	0	0	1.00
	2	-35	-32	-24	0.012	0.012	0.014	0.60	0.60	0.70
	4	-27	-17	-10	0.035	0.050	0.061	0.88	1.25	1.52
	6	-22	-15	-10	0.070	0.088	0.101	1.08	1.48	1.67
	8	-18	-14	-5	0.120	0.135	0.148	1.50	1.69	1.85
	10	-25	-17	-6	0.125	0.164	0.218	1.25	1.64	2.18
	15	-27	-20	-10	0.198	0.255	0.338	1.32	1.70	2.25
	20	-32	-27	-16	0.222	0.280	0.396	1.11	1.40	1.98
	30	-55	-40	-22		0.190	0.550		0.63	1.83
	50	-60	-60	-48	0	0	0	0	0	0
	100	-60*	-60*	-60*	0	0	0	0	0	0
100	0	-60*	-60*	-60*	0	0		0	0	1.00
	1	-60	-32	-15	0	0.005	0.010	0	0.05	0.95
	2	-27	-12	-20	0.015	0.022	0.019	0.75	1.10	1.75
	4	-18	-5	+1	0.050	0.070	0.070	1.25	1.75	2.62
	6	-13	+6	+12	0.093	0.114	0.157	1.55	1.80	4.71
	8	±0	+20	+25	0.188	0.264	0.377	2.35	3.30	4.14
	10	-11	±0	+34	0.194	0.248	0.414	1.94	2.48	3.80
	15	-12	-2	+18	0.316	0.402	0.572	2.11	2.69	2.50
	20	-32	-17	-8	0.225	0.396	0.500	1.12	1.98	1.33
	30	-55	-42	-30		0.150	0.400		0.50	0
	50	-60	-59	-47	0	0	0	0	0	0
	100	-60*	-60*	-60*	0	0	0	0	0	0

* Cloud point of 10 per cent alcohol—90 per cent gasoline blend prepared after indicated exposure.

SERIES II

The data for this series are found in table 3. The conditions more nearly simulate those of commercial storage in out of doors tanks under usual conditions of variation in humidity and temperature. Moreover the volume of the blend is greater than in Series I, permitting a somewhat greater and more constant counter pressure of the more volatile constituents of the blend. The data show the greatest water absorption for the 2 per cent blend. In comparsion the maximum water absorption per 100 cc. of alcohol for 100 per cent and 50 per cent humidity reported in table 2 is in the ratio of 1:0.48:0.28. The corresponding turbidity temperatures are $+20°$, $+10°$ and $-20°C$ respectively. The data of Series II show no measurable water absorption after thirty days for blends containing above 8 per cent alcohol. The blends containing 4-8 per cent alcohol are still stable, after 30 days, at $-50°C(-58°F)$.

TABLE 3. *Influence of alcohol content upon water absorption by 500 cc. blend in 1 liter bottles equipped with 2 mm. vent exposed indicated time out-of-doors. Initial cloud point below $-60°C$.*

Alcohol content of blend Vol. P'c't'g.	Cloud point		Water absorbed			
			cc/100 cc. Blend		cc/100 cc. alcohol in blend	
	15 days	30 days	15 days	30 days	15 days	30 days
0	−60*	−60*	0	0	0	0
1	−43	−60	0.005	0	0.50	0
2	−34	−20	0.018	0.027	0.90	1.35
4	−48	−48	0.014	0.015	0.35	0.38
6	−55	−47	0.008	0.025	0.13	0.42
8	−60	−50	0	0.025	0	0.31
10	−60	−60	0	0	0	0
15	−60	−60	0	0	0	0
20	−60	−60	0	0	0	0
30	−60	−60	0	0	0	0
50	−60	−60	0	0	0	0
100	−60*	−60*	0	0	0	0

* Cloud point of 10 per cent alcohol—90 per cent gasoline blend prepared after indicated exposure.

SERIES III

Reliable data on water accumulation in commercial storage are not available. Recently, the distribution of 10 per cent alcohol-gasoline blends on a commercial scale has given opportunity to study this problem.

On April 11, 1933, 84,000 gallons of the blend were prepared for the Earl Coryell Oil Company at their Lincoln Nebraska bulk station. The tanks used were 18 feet in diameter and 25 feet high. They were equipped with Morrison eight-ounce weight vent traps. The blend was easily prepared simply by pumping one tank car of anhydrous alcohol and nine tanks of gasoline together and then circulating by pumping, for a short time, from the bottom into the top. The cloud temperature of the blend was −49°C. After eighteen days, during which time about one third of the blend had been used, the cloud temperature was −51°C. On June 6, after 66 days storage, the last of the blend was withdrawn, the last gallon being taken for a sample. The cloud temperature was −59°C. The concentration of the alcohol had not changed appreciably while the distillation curve indicated

the loss of a small amount of a mixture of gasoline and alcohol of about a 10 to 1 ratio. The loss in moisture may be explained as due to the evaporation of a ternary mixture of alcohol, gasoline and water.

On April 28, 1933, 5,500 gallons of a 10 per cent alcohol-gasoline blend were prepared for the Square Deal Oil Company of Ames, Iowa. To the tank was attached a three-fourth inch vent consisting of an 8 inch length of three-fourth inch pipe and return bend. The blend was sampled daily. The last analysis, 13 days after blending and as the tank was emptied, showed a cloud temperature of —58°, which is identical with the original value.

SUMMARY

The water absorption by mixtures of anhydrous ethyl alcohol and gasoline has been determined under the most severe conditions, under conditions approaching actual storage conditions, and in actual commercial bulk storage tanks. The amount of water absorption is dependent upon complex conditions. There are involved the distillation characteristics of the gasoline, the concentration of alcohol, the surface-volume ratio, the volume of the blend, the type of vent, and fluctuations in temperature and pressure. For lower concentrations of alcohol, the water absorption by the blend is greater than for gasoline or alcohol alone. The point of maximum absorption varies with conditions of humidity and the other factors mentioned above.

The more nearly the experimental conditions approach those of actual commercial storage, the less water is absorbed. In the two instances examined with reference to storage of a 10 per cent blend in commercial tanks no water was absorbed during the time of observation, which was 66 days in one case. These results in commercial installation are in agreement with the statement by Hubendick that there has been no trouble from water absorption during the ten years commercial use of blends in Sweden (4).

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CONTENTS

Abstracts of Doctoral Theses

Note:—Complete copies of these theses can be consulted at the Library, Iowa State College, Ames, Iowa.

I. THE MANUFACTURE OF ARTIFICIAL ZEOLITES, AND
II. THE CONTROL OF ZEOLITE WATER SOFTENERS[1]

PAUL G. BIRD

From the Department of Chemical Engineering, Iowa State College.

One method of softening water commercially is the base-exchange or so-called zeolitic method in which the water to be softened is passed through a bed of base-exchange material. When hard water is passed through the bed, reaction I, which is typical of base-exchange, takes place.

$$Ca(HCO_3)_2 + Na_2Zeolite = CaZeolite + 2NaHCO_3 \qquad I$$
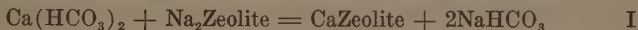
When the zeolite is exhausted it is treated with a salt solution to revivify it according to reaction II.

$$CaZeolite + 2NaCl = Na_2Zeolite + CaCl_2 \qquad II$$

Commercial base-exchange materials are obtained by processing natural materials such as greensand and ardmorite, or by compounding artificial zeolites from "secondary" raw materials. Artificial zeolites are generally made by bringing together dilute solutions of sodium silicate and one or more compounds of aluminum. These materials are combined to form a gel containing 90 per cent or more water, most of which must be removed to obtain a hard, durable, product suitable for use in a water softener. At present, this excess water is removed by filter pressing the gel and drying, or by drying alone, after which it is necessary to crush, screen, wash, and redry the material.

A major part of this investigation is concerned with the removal of this excess water from the gel or filter cake by freezing rather than by drying.

The gels used in the following experiments were made by mixing equal volumes of dilute solutions of commercial silicate and sodium aluminate. The stock solution of sodium silicate contained 24.7 per cent SiO_2, and 6.4 per cent Na_2O, and weighed 1.294 grams per cc. The sodium aluminate solution contained 32 per cent $Na_2Al_2O_4$ plus 10 per cent of NaOH, and weighed 1.400 grams per cc. The composition of the gels was expressed as the mol ratio of silica to alumina, and the concentration as gram mols of alumina per liter of gel.

"Whole-volume" gels were allowed to form. These gels were later broken up and filter pressed. The filter cakes were placed in water tight cans which were subsequently immersed for 48 hours in the brine tank of a refrigeration system where the temperature was nearly constant at 21°F. When frozen, the filter cakes were removed and allowed to thaw on a sloping floor. The material remaining consisted of moist particles of uniform shape. After drying at room temperature, the particles were screened, washed until they failed to react alkaline with phenolphthalein, and tested for capacity.

The testing was done in miniature water softeners made of 16 mm. glass tubing 34 cm. long. Hard water containing 376 p.p.m. of hardness was passed downward through the zeolite in the tubes at such a rate that it would no longer completely soften the water at the end of four hours. The capacity was calculated from the amount of water softened, the hardness of the water, and the volume of the zeolite. This is called the tube test.

Experiments were made to determine which ratio of silica to alumina yielded a product having the highest base-exchange value. This was done by keeping the alumina concentration constant, and varying the concentration of the silica in the gel. The maximum capacity was obtained when the ratio was between 2.0 to 1.0 and 2.5 to 1.0 in the range investigated.

In order to determine the best concentration of reagents the mol ratio was kept constant ot 2.2 to 1.0 while the concentrations of the silica and alumina were changed proportionally. The maximum capacity was obtained when the alumina concentration was between 0.100 and 0.125 gram mols per liter of gel.

Tests were made in which various substances were added to the aluminate or silicate solution before mixing. It was found that the addition of small amounts of soda ash, agar, casein, or sodium hydroxide, caused an increase in capacity, while the addition of sodium chloride, tri-sodium phosphate, borax, or large amounts of glue, casein, or soda ash, caused a decrease in capacity.

The effect of drying on the capacity the granules obtained by freezing was investigated by dividing some freshly thawed material into several lots, and then drying these portions separately. The capacity, on a volume basis, was found to increase in direct proportion to the amount of water removed.

Gels and filter cakes subjected to freezing yielded products having higher base-exchange than gels or filter cakes dried in the conventional manner.

It has long been known that fine zeolites have a greater base-exchange value than coarse zeolites because of the greater area per unit of volume. In a study of this relationship the capacities of closely screened portions of four artificial zeolites were determined. The capacities were found to be inversely proportional to the particle size for sizes greater than 0.3 mm., and the active layer in which the exchange took place was found to be less than 0.1 mm. in thickness. The particle sizes ranged from 0.25 to 2.0 mm. which includes the sizes used commercially.

Several artificial zeolites were tested for capacity by three methods. One portion of each zeolite was tested in a miniature water softener, a second portion in an electro-dialysis apparatus similar to that described by Bradfield, and a third portion was subjected to the "ultimate exchange" test. In Bradfield's apparatus or cell the exchangeable bases are dialysed by impressing an electrical potential across a porous medium, the bases being collected in the cathode compartment, then titrated. In the ultimate test a zeolite is repeatedly treated with $BaCl_2$ or $CaCl_2$ solutions, washed free from chloride ions, then repeatedly treated with sodium chloride solutions which are collected and analyzed for the alkaline earth element. The exchange values obtained by electro-dialysis and the ultimate test were in close agreement, but were greatly in excess of those obtained by the tube test. The tube test yielded values 25 to 35 per cent greater than the maximum exchange obtained in commercial installations.

When hard water is passed through a zeolitic softener the chemical and physical properties of the solution undergo a change.

There is a considerable increase in the conductivity of the tap water at Iowa State College after being softened by a zeolitic softener. Using a Wheatstone bridge and an alternating current galvanimeter type of relay, a softener was automatically controlled while in continuous operation by utilizing this difference in conductivity. It was found that a change in the water temperature of about 3°C. caused as great a change in conductivity as softening the water. However, it is possible to compensate for the temperature effect. Further investigation disclosed that a hard water may have an increase, a decrease, or no change in conductivity upon being softened.

The visible spectrum of the light from the spark produced by impressing a high potential across submerged platinum electrodes shows bands at 5,890 and 6,620 Angstroms common to both the hard and softened water at Iowa State College. Due to the presence of calcium and magnesium salts additional lines may be observed with hard water, thus furnishing a means by which hard water is readily distinguished from soft water, the identification being positive, accurate, and easily made. By means of a light sensitive cell and a suitable relay system the control of a water softener could be made fully automatic.

THE ACTION OF LIPOLYTIC BACTERIA ON SOME SIMPLE TRI-GLYCERIDES AND SOME NATURAL FATS[1]

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From the Department of Dairy Industry, Iowa State College

Many of the studies on the bacteria of particular importance in dairying have been confined chiefly to the action of the organisms on the carbohydrate and protein of dairy products. This probably is due to the fact that the fatty portion of dairy products is the least susceptible to bacterial action, but the difficulty of determining the action of bacteria on the fat is also a factor.

The work herein reported deals with a study of lipolytic bacteria and has been divided into four sections.

SECTION I. SOME CONSIDERATIONS OF THE NILE-BLUE SULFATE TECHNIQUE AND ITS APPLICATION TO THE STUDY OF BACTERIAL ACTION ON SIMPLE TRI-GLYCERIDES AND NATURAL FATS

Nile-blue sulfate, which, according to several workers, contains two constituents that give differential staining reactions with fatty acids and the tri-glycerides of these, proved to be a very useful indicator for the determination of the action of bacteria on fats. The two constituents which react differently with fats and fatty acids have been called Nile-blue and Nile-pink by Rettie (1).

One part of Nile-blue sulfate (as an alcoholic or an aqueous solution) was added to approximately 10,000 parts of beef infusion agar having a pH of 6.8 to 7.0, and the agar then sterilized. When this medium was melted for pouring, one part of sterile fat (emulsified with a 0.5 per cent agar solution) was added to approximately 200 parts of the agar and the mixture cooled to the desired temperature.

When the Nile-blue sulfate medium was used for the determination of the type and amount of bacterial action on a fat, the cultures were inoculated upon the surface of the solid medium, but when it was used to determine the numbers of lipolytic bacteria in certain materials it was poured into the inoculated petri dishes in the customary manner.

The studies on the color reactions between Nile-blue sulfate, and the simple and mixed tri-glycerides and fatty acids of which such glycerides are composed, indicate that (a) the Nile-blue of Nile-blue sulfate is definitely soluble in caproic, caprylic and oleic acids and decreasingly soluble in the saturated fatty acids above caprylic as the molecular weight increases, (b) the Nile-pink of Nile-blue sulfate is definitely soluble in tri-propionin, tri-butyrin, tri-caproin, tri-caprylin and tri-olein, in butter fat, lard, beef tallow, corn oil, cottonseed oil, olive oil, linseed oil and cocoanut oil, and decreasingly soluble in the tri-glycerides which are solid at 21°C. as their molecular weights increase, and (c) the Nile-pink is soluble in tri-n-valerin,

[1] Original Thesis submitted June, 1933.

tri-iso-valerin and tri-heptylin, as well as in hydrogenated cottonseed oil and lard.

The hydrolysis of the simple tri-glycerides by bacteria became more difficult as the molecular weights increased, tri-stearin being unaffected by bacterial action. Cultures of bacteria which hydrolyzed butter fat usually hydrolyzed the other natural fats and oils, as well as tri-butyrin and tri-olein, to about the same extent. Rarely did a culture hydrolyze tri-butyrin, tri-olein or one of the natural fats without hydrolyzing the others. The results indicated that any one of the common natural fats or oils used was a good material for the detection of lipolytic bacteria.

SECTION II. THE ISOLATION, IDENTIFICATION AND CLASSIFICATION OF LIPOLYTIC BACTERIA

Several hundred cultures of lipolytic bacteria were isolated by means of the Nile-blue sulfate method and, of this number, 159 were studied and identified insofar as possible. A study of the proteolytic abilities of lipolytic bacteria indicated that all the lipolytic organisms were not evidently proteolytic in litmus milk, but there was a fairly close agreement between the lipolytic and proteolytic abilities of the organisms studied. Each of 80 of the 159 cultures was added to sterile cream which was churned, and 58 (72.5 per cent) of these produced rancidity; this was the defect most commonly resulting in butter from the action of lipolytic bacteria. The type of colony and the amount of diffusible lipase produced by lipolytic organisms were useful as criteria in the grouping of the cultures.

The organisms most commonly isolated were identified as *Pseudomonas fragi, Ps. fluorescens, Achromobacter lipolyticum, A. connii* and a new species, *Ps. acidiconcoquens.* Four groups of cultures closely related to the typical *Ps. fluorescens* were named as varieties of this species; these are, *Ps. fluorescens var. zymogenes, Ps. fluorescens var. glycerolytica, Ps. fluorescen var. patula* and *Ps. fluorescens var. radians.*

Ps. fragi, A. lipolyticum, Ps. fluorescens (typical) and *Ps. mucidolens* were most active in the production of rancidity in butter.

SECTION III. THE NUMBERS OF LIPOLYTIC BACTERIA IN CERTAIN DAIRY PRODUCTS AND THE RELATIONSHIP OF THESE ORGANISMS TO RANCIDITY

Nile-blue sulfate medium (with butter fat) was used with the plate method for the determination of the numbers of lipolytic bacteria in certain dairy products.

The results showed that, (a) there were no lipolytic bacteria in the aseptically drawn milk examined, (b) there were considerable numbers of lipolytic bacteria in ordinary fresh milk, cream and unsalted, raw cream butter and (c) there were considerable numbers of lipolytic bacteria in unsalted, raw or pasteurized cream butter after holding for various lengths of time but very few in samples of salted butter. The lipolytic bacteria isolated from most of the products examined were gram-negative, non-spore forming rods, while in samples of salted butter micrococci usually predominated, and these types were not actively lipolytic. Rancidity was occasionally evident without large numbers of organisms but did not develop rapidly unless the development was accompanied by large increases in the numbers of lipolytic bacteria. The development of strong rancidity in butter was accompanied by a rapid decrease in the numbers of organisms.

SECTION IV. THE ABILITY OF LIPOLYTIC BACTERIA TO PRODUCE RANCIDITY IN BUTTER FAT, IN SOME OTHER NATURAL FATS AND IN SOME SIMPLE TRI-GLYCERIDES

For the purpose of this work, "rancidity" was defined as a defect which was characterized by the odor of the lower fatty acids, especially butyric acid, to distinguish it from oxidative rancidity or "tallowiness".

Because butter fat contains relatively large amounts of the triglycerides which are readily attacked by lipolytic bacteria and because other common natural fats and oils do not, it was thought probable that rancidity, as already defined, is largely confined to dairy products.

An attempt was made to produce rancidity in butter fat, corn oil, olive oil, tri-butyrin and tri-olein through the action of lipolytic bacteria. The organisms were inoculated into artificial media in which the various fats were dispersed with fine sawdust, shredded filter paper or 0.5 per cent agar.

The results showed that rancidity developed in butter fat in the 18 trials which involved nine lipolytic organisms, whereas it occurred with corn oil in only one of the 14 trials and never developed in any of the trials with olive oil, tri-butyrin or tri-olein. Although the data are limited they were sufficient to indicate that rancidity developed readily in butter fat, whereas tallowiness developed most frequently in the corn oil, olive oil and tri-olein media under similar conditions.

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THE PRODUCTION OF FURFURAL FROM CONCENTRATED SOLUTIONS OF XYLOSE[1]

RICHARD LINDLEY FOSTER

From the Department of Chemistry, Iowa State College

One of the outstanding achievements in the utilization of agricultural wastes for the manufacture of industrial chemicals is the development of the furfural industry. The raw product is the oat hull which might more properly be called an industrial waste rather than an agricultural waste since the oat hulls are in a way analogous to the industrial wastes of the packing industry. The potential yield of furfural from this source alone is tremendous and accounts for the large amount of research to find new uses for furfural. It should be pointed out also that additional sources of this chemical on a large scale are other industrial wastes which are already concentrated in the various centers and include such materials as cottonseed hulls, rice hulls, peanut hulls, straws (including corn stalks), corn cobs and the like.

The furfural is at present produced by heating the oat hulls at about 60 pounds pressure with usually about 5 per cent sulphuric acid for five or more hours (Miner, Trickey, and Brownlee[2] and Killefer[3]). Although the present process is a commercial success it possesses several disadvantages:

1. The yield in practice is only about 50-60 per cent of theoretical. While oat hulls should give about 20 grams of furfural per 100 grams of hulls, Brownlee[4] found the best yield to be 12.6 per cent using dilute sulphuric acid at 60 pounds of pressure for five hours with the optimum liquid-solid ratio of 0.27-1.0. It is generally conceded that the low yield of furfural is principally due to the polymerization of the furfural in the presence of the acid.

2. The recovery of the furfural from the aqueous system is a relatively expensive operation due to the low solubility of the furfural in the water.

3. The residue is so charred and charged with polymerized products as to make further utilization by recovery of the cellulose and lignin not feasible.

With these points in mind a method has been developed which will give higher yields, permit more ready and economical recovery of the furfural and leave the residue in better condition for further use in the chemical industries. It seemed advisable to make preliminary studies of the production of furfural from strong xylose solutions in order to establish general principles of procedure and then to apply these findings to agricultural raw products. In order to be industrially feasible these studies must be made on concentrated solutions of xylose, at least 10-25 per cent.

The first problem to be solved in the production of furfural from strong

[1] Original Thesis submitted August, 1932.

[2] Miner, Trickey and Brownlee. Chem. Met. Eng., **27**:299-303 (1922).

[3] Killeffer. Ind. Eng. Chem., **18**:1217-1219 (1926).

[4] Brownlee. Ind. Eng. Chem., **19**:422-424 (1927).

xylose solutions is the prevention so far as possible of the polymerization of the furfural in the reaction mixture. Two possibilities present themselves, first, the removal of the furfural from the reaction mixture as rapidly as it is formed, and second, the employment of less drastic reagents and lower temperatures.

This thesis deals with the quantitative and detailed studies of principles developed by Drs. Fulmer, Christensen and Hixon in their preliminary studies of this problem. Briefly their technique was as follows. The xylose solution with various combinations of NaCl and HCl was refluxed at atmospheric pressure with an immiscible solvent in which furfural is very soluble. Such solvents included toluene, benzene and carbon tetrachloride. Most of the work was done with toluene. The purpose of the solvent was to remove the toluene as formed and thus prevent its polymerization in the presence of the reaction mixture. The salt served two purposes, first, it decreased the solubility of the HCl and hence increased its reactivity at a given concentration, and second, it decreased the solubility of the furfural in the aqueous system and hence facilitated its more rapid and complete removal from the reaction mixture. The furfural in the toluene was analyzed by the use of a chainomatic Westphal specific gravity balance since it was found that the specific gravity of the toluene-furfural system is a linear function of composition.

The results may be summarized briefly from data obtained by use of toluene as the immiscible solvent. With the use of 20 per cent xylose with 0.50 N HCl and concentrations of NaCl of 0, 5, 10, 15, 20, 25, 30, 35, and 40 per cent the increase in furfural yield was respectively 0, 42, 44, 98, 138, 154, 203, 233, and 251 per cent showing the marked effect of the presence of the salt. The maximum yield of furfural was about 70 per cent of theoretical after refluxing for five hours. It was likewise found that with the use of 25 per cent NaCl the yield of furfural reached a maximum at 1.00 N HCl with no further increase, but a slight tendency to drop, at 1.25 N and 1.50 N.

Other salts were used in the presence of the HCl and also several salts without the addition of acid. The latter included NH_4Cl, $(NH_4)_2SO_4$, $NH_4H_2PO_4$, NH_4 tartrate, $ZnCl_2$, and $Al_2(SO_4)_3$ all of which yielded furfural, the action being due to their action as dehydrating agents. The combinations of NaCl-HCl with toluene were used on oat hulls with yields of furfural much above those at present obtained industrially.

As stated previously, this thesis is concerned with quantitative studies of the preparation of furfural from concentrated solutions of xylose using and extending the methods outlined above. These studies include the following: 1. the accurate determination of the specific gravities of toluene-furfural systems; 2. the relation of the relative volumes of toluene and solution to the yield of furfural; 3. the relation of the concentration of xylose to furfural yield; 4. the relation of furfural yield to various concentrations of HCl in the presence of various concentrations of NaCl for various periods of time; 5. the correlation of the increased yields due to the presence of the NaCl with the effect of the salt upon the "apparent" hydrogen concentration and the effect of the salt upon the solubility of furfural. The results of the studies will be briefly discussed in the order of the five headings mentioned above.

I. SPECIFIC GRAVITY OF TOLUENE-FURFURAL SOLUTIONS

As stated previously, the furfural content of the toluene-furfural solutions was determined by means of a chainomatic Westphal specific gravity balance. This analytical method is based on the determination of the specific gravities of pure toluene-furfural systems.

The furfural used to prepare these solutions was obtained by purification of technical grade furfural, furnished through the kindness of The Quaker Oats Company. It was treated with precipitated calcium carbonate to remove any acids present. The amount of carbonate added was about 10 per cent of the weight of the furfural. The mixture was stirred thoroughly and the carbonate allowed to settle. The supernatant liquid was distilled under atmospheric pressure and the middle portion of the distillate, boiling at 158-160°C. was collected. This fraction was again distilled. The portion of the distillate collected boiled at 159°C. (uncorrected). Evans and Aylesworth[5] gives the boiling point of furfural as 159.3°C. (uncorrected) and 161.7°C. (corrected). The furfural obtained in this manner was very nearly water white, having only a slight yellow color. The specific gravity was found to be 1.1578-25°/25° or 1.1544-25°/4°. This value agrees exactly with the specific gravity reported by Mains[6] which is 1.1544-25°/4°.

Mallinckrodt's C. P. toluene, used as the solvent in preparing the toluene-furfural systems, boiled at 109°C. The specific gravity was found to be 0.8644-25°/25°. In order to make the solutions of furfural in toluene correspond to the solutions obtained experimentally, the toluene was saturated with water. The specific gravity of the toluene after shaking with water was 0.8645-25°/25°.

The toluene-furfural solutions were prepared by diluting the required weight of furfural, measured from a burette, with toluene to a volume of 100 cc. The concentrations of the solutions are expressed in per cent (grams per 100 cc. of solution). The specific gravities of these solutions were determined by means of the chainomatic Westphal balance.

The relation of the specific gravity of the toluene-furfural system to the per cent of furfural is expressed accurately by equation (1) which was derived by the methods of least squares.

$$S_S = 0.002573X + 0.8645 \tag{1}$$

in which S_S is the specific gravity of the solution and X is the per cent of furfural in grams per 100 cc. of solution.

The concentration of furfural may likewise be calculated by the following relation,

$$S_S = S_T + \frac{S_F + S_T}{S_F} X \tag{2}$$

in which $S_S =$ Specific gravity of the solution
             $S_T =$ Specific gravity of the toluene
             $S_F =$ Specific gravity of the pure furfural
             $X \ =$ Grams of furfural per 100 cc. of solution.

Up to concentrations of 40 per cent furfural the values calculated by equation (2) are accurate to less than one per cent error (i.e., less than one part per 100). This accuracy is entirely within experimental error in the pro-

[5] Evans and Aylesworth, Ind. Eng. Chem., 18:24-27 (1923).

[6] Mains. Chem. Met. Eng., 26:779-784 (1922).

cedure used in the studies reported. This relationship holds equally well for the solvents benzene and carbon tetrachloride.

II.   THE RELATION OF RELATIVE VOLUMES OF TOLUENE AND SOLUTION TO THE YIELD OF FURFURAL

Volumes of toluene from 20 per cent to 300 per cent that of the reaction mixture gave practically the same yields of furfural from 20 per cent xylose in the presence of 0.50 N HCl and 40 per cent NaCl. A volume ratio of 1:1 was chosen as the most convenient for the experimental work.

III.   THE RELATION OF THE CONCENTRATION OF XYLOSE TO THE FURFURAL YIELD

Concentrations of xylose from 1.0 to 60 per cent were used with 0.50 N HCl and 40 per cent NaCl. There was a tendency for the yield of furfural to decrease slightly with increase in concentration of the xylose. However, up to 20 per cent the decrease was not great and this concentration was chosen as the most convenient to use in the succeeding experiments.

IV.   THE RELATION OF THE FURFURAL YIELD TO VARIOUS CONCENTRATIONS OF HCl IN THE PRESENCE OF VARIOUS CONCENTRATIONS OF NaCl FOR VARIOUS PERIODS OF TIME

Concentrations of HCl at 0.25, 0.50, 0.75, 1.00, 1.50, and 2.00 N were used each in the presence of 0, 5, 10, 15, 20, 25, 30, 35, 40, and 45 per cent NaCl for periods of 2 to 10 hours. In every case the presence of the NaCl increased markedly the yield of furfural, the increase being in some cases as high as 500 per cent. (See table 1). The maximum yield of furfural was 37 grams per 100 grams of xylose. Combinations of acid and salt refluxed with toluene for various periods of time which gave this maximum yield are 0.50 N HCl — 45 per cent NaCl for eight hours; 0.75 N HCl — 35 per cent NaCl for six hours; 1.00 N HCl — 35 per cent NaCl for four hours; 1.50 N HCl — 30 per cent NaCl for four hours; and 2.00 N HCl — 25 per cent NaCl for two hours.

V.   THE CORRELATION OF THE INCREASED YIELDS OF FURFURAL DUE TO THE PRESENCE OF THE NaCl WITH THE EFFECT OF THE SALT UPON THE ''APPARENT'' HYDROGEN ION CONCENTRATION AND UPON THE SOLUBILITY OF THE FURFURAL IN THE AQUEOUS SYSTEM

It was previously noted that the increased yield of furfural due to the presence of the NaCl was associated, *first* with a decrease of solubility and increase of the reactivity or chemical potential for the HCl and, *second,* with a decrease in solubility of the furfural in the aqueous system which would lead to a more rapid and complete removal of the furfural by the immiscible solvent.

It is well known that the addition of NaCl to HCl solutions has a significant effect upon the activity of the acid. The data obtained by Bowe[7] are especially pertinent to this problem. He compared the effect of various

7 Bowe. J. Phys. Chem. 31:291-302 (1927).

concentrations of NaCl, NaBr, and NaI upon the "apparent" hydrogen ion concentration, as determined by E.M.F. measurements, with rate of inversion of sucrose by these systems. He found these salts to increase both the "apparent" hydrogen ion concentration and the rate of inversion of sucrose by the 0.1 N HCl. In the presence of 4 N concentrations of the salts the "apparent" hydrogen was respectively about 5, 7, and 10 fold that of the acid alone with the rate of inversion of the sucrose increased in about the same order. The order of efficiency was Cl<Br<I. These findings are in harmony with the generalized statement by Buchanan and Fulmer[8] to the effect that if *chemical, X,* is bringing about *any reaction, A,* the addition of *any chemical, Y,* which in itself does not affect *reaction, A,* but decreases the solubility of *chemical, X* (that is increases its chemical potential) will intensify *reaction A.*

Applying the same principles to the effect of NaCl upon the furfural yield, the pH values of 0.25 N HCl in the presence of 0, 5, 10, 15, 20, 25, 30, and 35 per cent NaCl were determined and the "apparent" hydrogen ion concentration (C_H+) calculated. The percentage increase in C_H+ values (a) is given in table 1. In the table are likewise given the values for the per cent decrease in solubility of the furfural in the aqueous system due to the presence of the NaCl, (b). In the next column are values of (a) + (b). In the remainder of the table are given values, (c) for the per cent increase in furfural yield at various periods of time.

TABLE 1. *Effect of NaCl on the percentage increase in C_H+ (a), percentage decrease of Solubility of Furfural in 0.25 N HCl (b), and percentage increase in furfural yield from xylose by 0.25 N HCl (c)*

Pc't'g. NaCl	Pc't'g. Increase C_H+ (a)	Pc't'g. Decrease in Solubility (b)	(a) + (b)	(c) Pc't'g. Increase in Furfural Yield				
				2 Hrs.	4 Hrs.	6 Hrs.	8 Hrs.	10 Hrs.
15	37	9	46	45	50	69	50	35
20	80	20	100	116	97	115	108	91
25	158	30	188	194	161	196	174	132
30	272	34	306	330	240	281	222	197
35	390	43	433	490	320	361	294	235

Since for concentrations of NaCl less than 10 per cent, the yields of furfural are so small as to give somewhat erratic results by the analytical method employed, the yield at 10 per cent NaCl was taken as the reference point. It is evident that for the two-hour run the increase in yield of furfural due to the presence of the salt is directly proportional to the sum of the increase in C_H+, and the percentage increase in the chemical potential of the furfural, i.e., the two effects are strictly additive. For longer periods of time the per cent increase in furfural yield is not as great as for the two hour period. This is explicable by the fact that with increase in time the yields are approaching a maximum. Hence, the exact correlation for the two hour period is more significant than the results for the longer periods.

[8] Buchanan and Fulmer, Physiology and biochemistry of bacteria. The Williams and Wilkins Co., Baltimore (1930) Vol. III. p. 234.

SUMMARY

1. The specific gravities of systems of furfural and toluene are practically a linear function of composition, hence the percentage of furfural in toluene can be readily analyzed by a determination of the specific gravity of the system.

2. A technique has been developed for the preparation of furfural from strong solutions of xylose. The xylose solution with the dehydrating agent in solution is refluxed with an immiscible solvent, for example with toluene, and the yield of furfural estimated from the specific gravity of the solvent-furfural system.

3. Detailed studies were made of the yield of furfural from xylose using as the dehydrating agent various mixtures of HCl and NaCl for varying periods of time.

4. The NaCl markedly increases the yield of furfural in the presence of a given concentration of HCl. This increase is quantitatively correlated with the effect of the NaCl upon the activity of the acid and of the furfural. The latter two factors were determined in terms of the effect of the salt upon the ''apparent'' hydrogen ion concentration and upon the solubility of furfural in the aqueous phase.

REACTIONS OF INORGANIC COMPOUNDS WITH LIQUID HYDROGEN SULFIDE[1]

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Liquid hydrogen sulfide has been shown[2] to be a better solvent for organic substances than for inorganic. Ralston and Wilkinson[3] investigated the solubility and hydrolysis of inorganic chlorides in liquid hydrogen sulfide. Satwalekar[4] studied the action of metals and oxides on liquid hydrogen sulfide.

The purpose of this work was to investigate a number of reactions that take place readily with water and to try to bring about the similar reaction with liquid hydrogen sulfide.

EXPERIMENTAL

The liquid hydrogen sulfide was prepared in the apparatus designed by Quam and later modified by Meintz and Wilkinson[5]. Some criticism of the use of phosphorus pentoxide as a drying agent for hydrogen sulfide has been made by Lilienfeld and White[6] but no evidence of any oxidation of the hydrogen sulfide with the formation of sulfur dioxide was observed in the hydrogen sulfide made by the above apparatus.

Calcium oxide and calcium carbide both react readily with water to form the hydroxide and with the carbide acetylene is also liberated. When these are treated with liquid hydrogen sulfide similar reactions take place. With lime the solid left after evaporating off the excess of hydrogen sulfide is not of constant composition but varies with different preparation. The results below are the averages of several preparations:

Compounds	CaS	Ca(HS)$_2$	Ca(OH)(SH)	Found
% S	44.44	60.35	35.55	42.92
% Ca	55.56	37.73	44.44	47.9

These data indicate that the product is a mixture of CaS and Ca(SH)(OH) since the percents of sulfur and calcium are lower than in the pure CaS. The fact that the S is low shows that there can be no Ca(SH)$_2$ present.

The analysis of the residue from the calcium carbide indicated that the reaction goes to completion rather slowly and that the sulfide is chiefly formed but with some Ca(SH)$_2$. It is difficult to get check results because of the continued loss of H$_2$S from the Ca(HS)$_2$. The purity of the CaC$_2$ was 95 per cent and some of this was always enclosed in the particles of residue. This would lower the per cent of sulfur and raise that for calcium. The average of several preparations showed 51.35 per cent calcium and 37.32 per cent sulfur.

1 Original Thesis submitted August, 1930.

2 Antony and Magri, Gazz. chim. ital. 35, 206, (1905); Steele, McIntosh and Archibald, Trans. Roy. Soc. (London).

3 Ralston and Wilkinson, J. Am. Chem. Soc. 50, 258 (1928).

4 Satwalekar—Doctoral Thesis, Iowa State College 1928.

5 Meintz and Wilkinson, J. Am. Chem. Soc. 51, 803 (1929).

6 Lilienfeld and White, J. Am. Chem. Soc. 52, 887 (1930)

A small amount of yellow oil with an odor similar to a mercaptan was formed by the reaction between hydrogen sulfide and acetylene. This is the thio acetic aldehyde.

$$C_2H_2 + H_2S = CH_3CHS$$
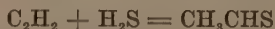
Solid calcium and potassium sulfides do not react with CS_2 in liquid H_2S to form the thiocarbonates. Hydrated sodium sulfide reacts with CS_2 in liquid H_2S to form two liquid layers the bottom one consisting of sodium thiocarbonate dissolved in the water of hydration of the sodium sulfide. The top layer consists of the excess of CS_2 dissolved in the H_2S. Liquid ammonia reacts with an alcoholic solution of H_2S and CS_2 to form the compound, ammonium dithiocarbonate, $(NH_4S)(NH_2)CS$. An analysis of the yellow solid formed in the reactions showed

N = 25.45 per cent, S = 58.26 per cent, Theoretical N = 25.47 per cent,
S = 58.19 per cent

Liquid hydrogen sulfide and liquid sulfur dioxide have been reported by some workers as being quite inert and by others as reacting explosively. In this laboratory we have found the mixture to be inert if kept cold ($-68°C$) but if the temperature is allowed to rise a reaction starts at the boundary between the two immiscible liquids and increases in violence until the mixture explodes. Extreme precautions were taken to have both liquids dry (with P_2O_5) before mixing.

With the oxy or yl chlorides of the non metals liquid hydrogen sulfide brings about thiohydrolysis as for example with sulfuryl, nitrosyl and thionyl chlorides

$$SO_2Cl_2 + H_2S = SO_2(SH)_2 + 2HCl$$
$$NOCl + H_2S = NOSH + HCl$$
$$SOCl_2 + H_2S = SO(SH)_2 + 2 HCl$$
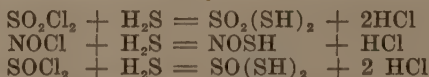
These thiol bodies are all unstable and break down liberating free sulfur very readily. Also more or less of the yellow oily hydrogen persulides are always formed, especially H_2S_3.

Phosphoryl chloride dissolves completely in liquid hydrogen sulfide at room temperature but crystallizes out as a white solid at $-68°C$. It reacts very slowly with the H_2S, at that temperature, forming a small amount of yellow solid which is sulfur. This comes from the very slow oxidation of the H_2S by the $POCl_3$.

Vanadyl tri-chloride reacts vigorously with liquid H_2S forming a brown solid. Some sulfur is always present due to oxidation of H_2S by the penta valent vanadium. If the $VOCl_3$ is dissolved in benzene the reaction velocity is slowed down somewhat and less sulfur is formed. Two reactions are apparently involved, the reduction of the vanadium by the H_2S and the replacement of the oxygen by sulfur. The second reaction is not complete. Any given preparation will give a constant analysis but different preparations vary. A typical analysis is as follows:

V   27.74
S   20.14
Cl   33.08
H + O (by difference) 19.04

These data fall between the two extremes of the compounds $VSCl_3$ (V = 26.9, S = 16.9, Cl = 56.2) in which the oxygen of $VOCl_3$ has been replaced by sulfur but no reduction of the vanadium has occurred and the compound $VOCl.H_2S$ (V = 37.3, S = 23.5, Cl = 26) in which reduction has taken place but the oxygen has not been replaced although H_2S has been added. This may be looked upon as $V(OH)(SH)Cl$. The body obtained in the above reaction is between these two and the substance obtained will depend upon how far the two reactions have gone.

THE RELATIONSHIPS OF A LIPOLYTIC ORGANISM TO RANCIDITY OF BUTTER[1]

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The data herein reported deal with the study and identification of an organism which was found in considerable numbers in two samples of rancid butter. The presence of the same organism in the two samples of butter suggested its causal relationship to the rancid condition. Preliminary churning trials, using pasteurized cream to which the organism had been added, revealed that it was capable of producing a marked rancidity in butter.

The organism isolated possessed two unusual characteristics when grown in litmus milk. The first of these was the production of a small ring of acid curd at the surface of the tube, while the remainder of the tube of milk remained uncoagulated for a considerable period of time. The second characteristic was the production of an odor similar to that given off by the flower of the Mayapple or mandrake (*Podophyllum peltatum*). Organisms producing similar changes in litmus milk had previously been encountered rather frequently on plates poured from dairy products but their relationship to the production of rancidity in butter had not been recognized.

Following the isolation of the organism from the two samples of rancid butter a number of dairy products were examined for its presence. During this search the organism was isolated from 12 samples of normal ice cream, 31 samples of rancid butter, 5 samples of milk, 3 samples of cream, and 2 samples of evaporated milk.

After 53 cultures had been isolated from various dairy products the cultures were subjected to a sytematic study. The organism was found to be psychrophilic, aroma-producing, gram negative, non spore-forming, polar flagellated rod, which was capable of hydrolyzing fat.

The systematic study of the organism revealed that considerable variation occurred in the types of colonies produced by the cultures. Colony variations occurred in cultures which had been purified by plating and in other cultures which had been purified by single cell isolations. One of the four cultures studied yielded five types of colonies; one yielded four types and two cultures each yielded three types.

A number of bacteria capable of hydrolyzing fat have been described. Eichholz (1) described an organism which produced a strawberry-like aroma in various media. Grüber (2, 3) described two such organisms. The characteristics of these previously described species seemed to agree rather closely with the description of the organism isolated from rancid butter and various other dairy products. If the different colony types which were secured from the organism isolated are considered, each type can be identified with one of the three organisms mentioned above. Thus the O type can be identified with *Bacterium fragi* Eichholz; the S type can be identified with *Pseudomonas fragariae* II Grüber; and the R type can be identified

with *Pseudomonas fragariae* I Grüber. *Bacterium fragi* Eicholz was the first of the organisms to be described and this species name should be retained. The characteristics of the organism are such that it seems to belong to the genus Pseudomonas and the name *Pseudomonas fragi* nov. comb. is therefore suggested for it.

Experiments designed to determine differences in the biochemical activity of the variant types revealed the following points. Variant types could be secured (from parent cultures with marked fat splitting action) which were unable to split fat. The S type colonies from all four cultures studied were able to hydrolyze fat. O type colonies which were unable to hydrolyze fat were secured from all four of the cultures studied. However, an otherwise typical O type colony was secured from culture A which did not hydrolyze fat. The fat splitting ability of the R type colonies varied with the culture studied, those secured from two of the cultures being able to hydrolyze fat while the R type colonies secured from the other two were unable to produce this change.

The data secured on the ability of the various types to split the protein of milk show that there was considerable difference in the ability of the different types to produce this change. In general the original cultures and the S type variants caused considerable increase in the amount of soluble and amino nitrogen when they were grown in milk. With all of the O type cultures there was actually a decrease in the amount of soluble and amino nitrogen. The R type variants produced quantities of soluble and amino nitrogen which were between the amounts produced by the S and O types from the corresponding culture.

The section of the work dealing with butter made from pasteurized cream containing the organism showed that the organism could grow in butter held at low temperatures until large numbers were present. The effect of salt was very marked in restraining the development of the organism in butter. The effect of salt on the number of viable organisms present was evident very soon after the salt was added. Butter culture did not seem to have a very marked action in restraining the growth of the organism in butter.

The total amount of acid in the butter increased rapidly until after a relatively short storage temperature there was a large increase in the acid present in the butter even at the low temperature used. The amount of acid present was greatly influenced by the addition of salt to the butter. The acidity in salted butter never reached the high level that was reached in the unsalted sample from the same source. As the salt content of the butter increased the amount of acid decreased. When 10.0 per cent butter culture was added to the cream before churning, the resulting butter never contained as much acid as the control without butter culture. The same inhibiting effect was noticed when the butter culture was worked into the butter after churning.

The volatile acid content of butter containing the organism was higher than the volatile acid content of the uninoculated controls. Determinations made on butter containing salt revealed that the amount of volatile acid present in the butter was greatly influenced by the presence of salt. As the concentration of salt increased the amount of volatile acid decreased. Butter culture tended to inhibit the development of volatile acid.

Butter made from cream containing the organism regularly exhibited a characteristic sequence of changes. The first of these changes was the disappearance of the heated flavor and odor resulting from the high pasteur-

ization temperature used. At about the time the heated flavor had reached a minimum an abnormal flavor had appeared. When first noticed this was not definite but with continued storage the abnormal flavor was identified as rancid. The rancid condition rapidly increased.

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SOME PROPERTIES OF THE SOIL SOLUTION AND THE COLLOIDS IN CERTAIN IOWA SOILS[1]

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The first part of this work consisted of some preliminary studies on the colloidal properties of four Iowa soils. Later, samples of nine soils were taken in different parts of the state, air dried, and then analyzed in the laboratory for various constituents. A complete description of each of the soils used in the experiments is given and a map of Iowa shows the soil areas of the state and the approximate points where the soil samples were taken.

A broad historical review of the early literature on soil solution and soil colloid studies is given, with particular reference to soil extracts. Many of the methods used by early workers in extracting the soil solution were tried, but were all discarded in favor of the 1:5 water extract. Water extracts (considered to be the soil solution) were prepared in this way from the nine soils and the extracts were analyzed for the same constituents as were determined in the soils. The base exchange properties were determined and compared with the results of the chemical analyses secured from the soils and soil extracts. The colloids were separated from some of the soils, and their importance to bacterial action, both aerobic and anaerobic, was studied. Throughout the work the official methods were used insofar as official methods are available. The soil and soil solution constituents are reported in percentage, while the base exchange data are given in milligram equivalents. Where correlations were made between the soil, soil solution and base exchange properties, the data were recalculated and put on the milligram equivalent basis. These recalculated data are all illustrated graphically.

The collodial content of the soils, total carbon, organic carbon, and the pH of the soils were determined. The results indicated that there were differences in the colloidal content of each soil, which might be useful in distinguishing soil types. The organic matter present was found to be chiefly colloidal in nature.

The analytical data obtained indicated almost a direct correlation between the phosphorus, nitrogen and carbon in the soils. That is, where nitrogen was high, carbon and phosphorus were also high, and where one of the elements was low, the other elements tended to be low. There was an inverse relationship between the silica and the sesquioxides. When the silica was high, the sesquioxides were low, and when the silica was low, the sesquioxides were high. This relationship was shown very well in the case of each of the nine soils. Some distinct differences were noted between the different C:N and $\dfrac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratios. How much significance could be attached to these differences, however, is a question. The analyses of the

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soil solutions showed that the water soluble minerals were not present in the soil extracts in the same proportion as they were found in the soils, at least no close similarities could be detected. Extracts made by various dilutions of soil and water ranging from 1 part of soil to 5 of water, up to 1 part of soil and 80 of water showed the increasing solubilities of the minerals with the higher dilutions. Some striking differences were found in the soluble salts obtained from these dilutions on the various soils. The Webster silty clay loam which is considered very productive gave the highest water soluble salt content. No relationships could be noted between the amounts of sodium, potassium, or calcium found in the soil solution as compared to the same elements found in the soil.

Some of the base exchange properties of the same soils were studied. It was found that the M.E. of exchangeable bases were directly related to the loss on ignition. The M.E. of exchangeable sodium, potassium, and calcium were not apparently related to the amounts of the same constituents found in the soils or soil extracts. The Webster silty clay loam soil, which may be termed an alkali soil, presented difficulties in the exchangeable calcium determination. The carbon-nitrogen ratio tended to follow the same trend as the loss on ignition and the exchange capacity of the soils. The pH of the soils and the pH of the soil extracts were approximately the same and the M.E. of exchangeable hydrogen showed an inverse relationship to the pH of the soil and soil extract. That is, where the pH was low, the exchangeable hydrogen was high, or vice versa. The P_2O_5 content and the M.E. of exchangeable bases tended to be inversely related to the $\dfrac{SiO_2}{R_2O_3}$ ratio for all of the soils studied.

The colloids that were separated from the soils were used in various proportions as nutrients for different species of bacteria. The effect of the colloids on bacterial action was measured by increases or decreases in gas production as were shown on the differential manometers used. Sterile colloids plus dextrose inoculated with a mixed culture of anaerobic organisms (which was isolated from the soil) gave a much greater gas production than either the colloid or the soil inoculated with the same culture of anaerobic organisms but without the dextrose. This gas production was also more than was produced when sterile soil plus dextrose or sterile colloid or sterile soil were inoculated with the same culture. After 36 hours of growth, the gas production from the sterile colloid plus dextrose by the anaerobic culture was more nearly the same as from the sterile soil plus dextrose by the same culture of anaerobes. The soil colloids were found to stimulate growth of *Rhizobium leguminosarum, Bacillus radiobacter,* and *Azotobacter chroococcum* when they were included in the media used for these organisms. It was found that the colloids could be substituted for the mannitol which is commonly used in the media. However, the organisms grew better when both the mannitol and colloids were used.

This work showed that the colloids may play an important role as nutrients and as a habitat for the microflora found in our soils.

LIFE EXPECTANCY OF PHYSICAL PROPERTY[1]

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This study was undertaken with a two-fold objective: First, to collect and compile life experience data of physical property; and Second, to analyze this experience and deduce such mortality laws and relations as may become evident.

Under the first objective 52 mortality tables were collected and compiled. Of these, 5 are of equipment used in water works systems, 14 in telephone systems, 5 in telegraph systems, 6 in light and power systems, and 21 in railroad transportation systems.

Upon careful comparison of the survivor curves of these 52 groups it was found that they could be fairly well represented by seven distinct types varying in steepness of slope from approximately a vertical line to a straight line drawn between 100 per cent at zero age and 0 per cent at 230 per cent age.

All of these types could be well represented by the Compertz-Makeham formula used for humans, the various constants having the values shown in table 1.

TABLE 1. *Values of constants of Gompertz-Makeham formula for seven type mortality curves*

Type	k	s	g	e
I	100.0	00	.9999	2.83
II	100.05	00	.9995	2.018
III	110.1	1.047	.9085	1.291
IV	121.65	1.059	.8130	1.222
V	125.9	1.047	.7943	1.197
VI	138.04	1.047	.7245	1.164
VII	149.2	1.035	.6702	1.137

The analysis of the distribution or frequency curves for the seven types showed that they could be reasonably well represented by Pearson's Type I equation with the constants having the values given in table 2.

TABLE 2. *Frequency equation constants for seven frequency groups*

Type	r	b	m_1	m_2	a_1	a_2	y_o
I	27.875	17.821	22.474	3.400	15.474	2.342	34.15
II	22.6036	19.3897	11.1285	9.4751	10.4728	8.917	19.28
III	18.541	23.0014	9.022	7.519	12.5457	10.4557	14.79
IV	13.883	24.747	5.824	6.059	12.129	12.618	11.82
V	9.0192	23.651	3.387	3.632	11.413	12.238	9.86
VI	8.3268	25.622	2.4995	3.8272	10.1225	15.4995	8.90
VII	5.3585	24.0966	1.1986	2.1599	8.5997	15.4969	7.574

Probable life at any age was defined as the sum of age and expectancy at that age. Plotting probable life against age showed these curves to be of parabolic form with the constants for the seven types having the values tabulated in table 3.

TABLE 3. *Constants for parabolic equations for seven type probable life curves*

Types	Coefficient (a)	Exponent (b)
I	.000000000002533	6.2497
II	.0000005233	3.6971
III	.00004767	2.7964
IV	.0005422	2.3212
V	.003332	1.965
VI	.01228	1.7202
VII	.03953	1.500

On the assumption that these seven types represented typical properties undergoing continuous renewal, the total annual renewals to be made during each age interval were calculated. These calculations were extended until the annual renewals became constant at the normal value given by the ratio of 100 to average life. An analysis of these renewal curves showed that they were exponentially damped sinusoidal variations with respect to time and could be expressed by

$$y = d\,e^{-ax} \sin bx$$

The values which represented the seven types are given in table 4.

TABLE 4. *Values of seven types*

Type	d	a	b
I	21.70	0.00284	0.0633
II	20.00	0.00731	0.0608
III	17.06	0.01122	0.0574
IV	12.30	0.01332	0.0524
V	7.57	0.01378	0.0482
VI	4.60	0.01375	0.0400
VII	3.81	0.01312	0.0405

CONCLUSION

Since the Compertz-Makeham formula could be fitted to the seven survivor curves over the entire range showed that this expression was more applicable to physical property than to humans. The fact that the distributions were of the Pearsonian Type I was evidence that these were typical phenomena. Furthermore, the fact that probable life was parabolic with respect to time, and annual renewals exponentially damped oscillations was further evidence that these relations are typical of natures most common phenomena.

THE INFLUENCE OF COPPER ON THE GRAPHITIZATION BEHAVIOR OF WHITE CAST IRON[1]

Louis Lykken

From the Department of Chemistry, Iowa State College

An investigation of the influence of copper additions on the graphitizing behavior of commercial white cast iron seemed to be of some importance, (a) because of the lack of quantitative information on this subject (1) (2) and (b) because the use of copper bearing iron and steel is coming to be more important. In order that no difficulties should arise due to the temperatures to be used in the annealing process, it was deemed necessary to determine the influence of copper on the transition (A_{r_1}) temperature of the cast iron used. To investigate fully the influence of the copper content on the decomposition of the massive cementite, as well as on the break down of the solid solution, it was decided to subject the desired samples to the two-cycle malleabilizing heat treatment developed by Hayes and Diedericks (3).

DEVELOPMENT OF WORK

A. PRPARATION AND CHEMICAL COMPOSITION OF THE ALLOYS

Twenty-one alloys were prepared from commercial white cast iron base. Eleven of these alloys contained a varying copper content up to four and one-half per cent. The other ten alloys contained one per cent copper in combination with varying carbon and silicon content.

Three thousand grams of white cast iron were melted in a plumbago crucible by means of a 30. K. W. Ajax induction furnace. When the iron was just fluid, the calculated amount of copper and ferro-alloys were added. When the molten alloy had reached 2500°F., the melt was poured into a damp sand flask. The flask was not broken until the casting had reached a temperature below red heat.

The chemical compositions of the prepared alloys (#11 to #31) and of the white cast iron base (#R) are given in table 1.

B. THE INFLUENCE OF THE COPPER COMPOSITION ON THE A_1 TEMPERATURE OF WHITE CAST IRON

The nature of the proposed heat treatment made necessary a fair knowledge of the Ar_1 temperature of the alloys to be heat treated. To this end differential heating and cooling curves were run on annealed samples using a Leeds and Northrup apparatus. The cooling and heating curves were run at a rate of 20° to 25°F. per minute. Besides copper, the alloys used contained 2.05 per cent C, 0.65 per cent Si, 0.21 per cent Mn, 0.031 per cent S and 0.141 per cent P. The results of the thermal analysis are given in table 2.

C. THE PROCESS OF HEAT TREATMENT

Samples were placed in iron pipe containers and surrounded with granular carbon. All heating trials were made in an automatically controlled Hump furnace. After the heat treatment, the samples were allowed to cool in the pipe-containers.

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[1] Original Thesis submitted June, 1933.

TABLE 1.

Alloy No.	Percentage of Chemical Composition						Fracture of casting
	Cu	C	Si	S	Mn	P	
11	4.47	2.33	0.81	0.033	0.24	0.119	White
12	3.10	2.52	0.84	0.029	0.22	0.120	,,
13	2.26	2.49	0.81	0.036	0.25	0.120	,,
14	1.94	2.54	0.81	0.033	0.25	0.123	,,
15	1.35	2.52	0.82	0.028	0.25	0.123	,,
37	1.03	2.60	0.85	0.061	0.25	0.127	,,
17	0.76	2.59	0.85	0.036	0.23	0.120	,,
18	0.60	2.60	0.84	0.034	0.23	0.120	,,
19	0.40	2.60	0.84	0.033	0.25	0.120	,,
20	0.17	2.60	0.87	0.031	0.25	0.120	,,
21	0.01	2.63	0.84	0.033	0.25	0.110	,,
22	0.92	2.84	0.84	0.036	0.24	0.115	,,
23	0.92	3.08	0.82	0.030	0.25	0.115	Mottled
24	0.94	3.28	0.83	0.030	0.24	0.115	Gray
25	0.98	3.47	0.83	0.036	0.25	0.115	,,
26	0.91	2.71	0.95	0.036	0.28	0.115	Mottled
27	0.94	2.61	1.07	0.033	0.26	0.115	,,
28	0.97	2.58	1.14	0.034	0.25	0.115	Gray
29	0.95	2.54	1.22	0.033	0.24	0.120	,,
30	0.94	2.08	0.83	0.030	0.25	0.107	White
31	0.92	2.50	0.68	0.030	0.25	0.107	,,
R	0.00	2.51	0.88	0.042	0.24	0.136	,,

TABLE 2.

Sample #	Pc't'g Cu	Thermal Values			
		Cooling		Heating	
		A_r(°F)	Rate	A_c(°F)	Rate
10	0.04	1365	20°F./min.	1405	20°F./min.
8	0.39	1350	,,	1405	,,
7	0.50	1345	,,	1400	,,
6	0.72	1340	,,	1395	,,
6	0.72	1345	,,	1400	,,
4	0.94	1330	,,	1390	,,
3	1.46	1310	,,	1385	,,
1	3.00	1290	,,	1390	,,

In order to determine the time needed to decompose the massive Fe_3C, the ''white-fracture'' samples were placed in the furnace maintained at 1700°F. ($\pm$ 10°F.). After the samples had been heated the required time, the charge was cooled in the furnace to 1450°F. (for one hour) before removing. The progress of the heat treatment was determined by examining the polished section for Fe_3C after etching with alkaline sodium picrate.

A similar treatment was used to determine the time necessary to complete the graphitization of the austenite. Fresh samples were heated ten hours at 1700°F. and then cooled to 1450°F. at a rate of 50°F. per hour. The furnace was then cooled from 1450°F. to 1275°F. in ten minutes. The samples were then maintained at 1275°F. $\pm$ 10°F. for some time while a sample-container was taken out every hour. A polished section was examined for the presence of pearlite, after etching with 5 per cent nital.

PRESENTATION OF RESULTS

The time needed to complete the graphitization, of the copper-bearing cast iron, at 1700°F. and 1275°F. is given in table 3.

TABLE 3.

Alloy	Weight percentage			Time for decomposition of massive cementite at 1700°F.	Time for graphitization of eutectoid carbide at 1275°F.
	Cu	C	Si		
11	4.47	2.33	0.81	6 hours	3 hours
12	3.10	2.52	0.84	5 ,,	3 ,,
13	2.26	2.49	0.81	5 ,,	3 ,,
14	1.94	2.54	0.81	5 ,,	3 ,,
15	1.37	2.52	0.82	6 ,,	3 ,,
37	1.03	2.60	0.85	7 ,,	4 ,,
17	0.76	2.59	0.85	7 ,,	4 ,,
18	0.60	2.60	0.84	7 ,,	4 ,,
19	0.40	2.60	0.84	7 ,,	4 ,,
20	0.17	2.60	0.87	8 ,,	5 ,,
21	0.01	2.63	0.84	8 ,,	4 ,,
30	0.94	2.08	0.83	7 ,,	8 ,,
37	1.03	2.60	0.85	7 ,,	4 ,,
22	0.92	2.84	0.84	6 ,,	3 ,,
23	0.92	3.08	0.82	5 ,,	3 ,,
31	0.92	2.50	0.68	7 ,,	6 ,,
37	1.03	2.60	0.85	7 ,,	4 ,,
26	0.91	2.71	0.95	6 ,,	4 ,,
27	0.94	2.61	1.07	5 ,,	4 ,,
R	0.00	2.51	0.88	8 ,,	5 ,,

Reviewing the data found in table 3, one finds that the times for the secondary stage are unusually short. However, photo-micrographs show that the samples were completely graphitized in the indicated time. The writer has no definite explanation of these abnormal results.

Two per cent copper shortens the total annealing time about 22 per cent; copper accelerates both stages of the graphitization equally. Above two per cent of copper, there is no further effect on either stage. Carbon and silicon have the same influence in copper-bearing castings as in ordinary white cast iron. Gray casting were produced with 3.28 per cent carbon (0.85 percent Si) and 1.15 per cent silicon (2.58 per cent C) in the presence of 1 per cent copper.

The presence of copper does not markedly influence the structure of the white cast iron. However copper tends to refine the grains of the malleabilized castings. The ferrite and pearlite of copper-bearing castings seem to etch much faster than the pure constituents. The influence of copper on the physical properties of the alloys was not investigated.

SUMMARY

1. A study has been made of copper on the position of the A_{321} point of a white cast iron suitable for malleabilizing. This critical temperature is lowered 45°F. by three per cent of copper.

2. The influence of copper on the malleabilizing tendency of white cast iron has been studied quantitatively. This research indicates that copper shortens the time in both stages of graphitization.

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THE DIGESTIBILITY OF MILK IN VIVO AS AFFECTED BY CERTAIN PHYSICAL TREATMENTS[1]

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From the Department of Animal Husbandry, Iowa State College

The digestibility of milk from which the fat had been removed by means of a centrifugal separator, was measured in vivo with dairy calves. The milk was fed as raw milk, pasteurized milk, boiled milk and autoclaved milk.

Curd-tensions were determined by a modification of the Hill method (Utah Bul. 227) on all samples both before and after heat treatment. Pasteurizing at 142°F. for 30 minutes in a vat pasteurizer reduced the curd tension about 20 per cent, boiling the skim milk for 3 minutes in an open container on an oil bath lowered the curd tension about 80 per cent and autoclaving the milk at 242°F. for 15 minutes reduced the curd tension to zero.

These milks were fed to young calves which had gastric fistulae. A tube was passed through such a fistula into the abomasum by way of the reticulo-omasal and omaso-abomasal orifices and samples of the gastric contents withdrawn for analysis. The tube was frequently used for introducing the milk to be studied to the stomach instead of allowing the calf to drink the test meal. The rate of digestion was determined by measuring the rate of disappearance of the milk curd from the stomach. In addition, hourly measurements of the total acid, free acid and hydrogen-ion concentration of the gastric contents of the calves were made. The quantity of milk fed was two (2) liters in each trial.

Raw milk usually disappeared from the stomach in from 12 to 18 hours after ingestion. The shortest test on raw milk lasted 10 hours and the longest test 29 hours. Boiled milk usually disappeared from the stomach in from 8 to 12 hours but remained as long as 22 hours in one case. Autoclaved milk acted very similarly to boiled milk. The extremes for autoclaved milk were not so great, however, being 8 to 12 hours. Limited data showed that pasteurized milk is digested in about the same time as raw milk. Comparisons of the various types of curd indicated that raw and boiled milk digested at about the same rate during the first 3 to 6 hours, after which, the curd of boiled milk disappeared much more rapidly.

Acidity curves on both raw and boiled milk rose similarly until about the 8th or 9th hour. The curves for raw milk leveled out from this point on until about the seventeenth hour when a marked decline took place. The curves for boiled milk, however, showed a sharp decline from the 8th hour on.

Boiled and autoclaved milk left the stomach faster than raw milk, not because the gastric juice varied in acidity but more likely because heating changed the curd of the milk in some way so as to allow the gastric juice more curd surface to attack. This change is definitely shown by the change in curd tensions of the milk before and after heat treatment.

A normal calf without a gastric fistula was fed four pounds of mixed

[1] Original Thesis submitted March, 1932.

whole milk, from the college herd, and autopsied eight hours after feeding. The stomach contents were then measured as a check on the fistulae calves. The results were very similar in quantity and state of digestion to those of the experimental calves for the same time after feeding. The data indicate that fistulae operations do not disturb the normal process of digestion.

While making the studies with fistulae-calves it was found that raw milk coagulated in the stomach of the calf in from one to ten minues. Boiled milk and autoclaved (242°F.) milk coagulated more slowly in the stomach—usually requiring from 8 to 15 minutes. The shortest clotting time for boiled milk was two minutes. One sample each of boiled and autoclaved milk did not quickly form a consistent curd mass but resembled thick cream soup two hours after ingestion.

X-ray photographs were taken of calves' stomachs. These pictures were taken on separate days and at intervals varying from 6 to 13 hours after feeding two liters of skim milk containing 100 grams of barium sulphate. After the pictures were taken the stomach contents were removed (via gastric fistula) and weighed. These weights were then compared with the volume of the stomach contents as shown in the pictures. Although the curd in the stomach is visible in the pictures it is believed the X-ray method of studying digestion in the calf is only fair at best. Barium sulphate, fed along with the milk, coats the walls of the stomach and tends to mask the actual curd content.

Standard clinical methods were adopted to study the effects of heat on milk ingested by a human subject. A Rehfuss stomach tube was swallowed by the author and kept in the stomach throughout each trial. Samples of gastric juice were withdrawn and analized for total acid, free acid and hydrogen-ion concentration. The resultant acidity curves add proof that boiled milk and autoclaved (242°F.) milk leave the stomach in a shorter time than does raw milk. The 500 cubic centimeter samples of boiled and autoclaved milk were sometimes digested at the end of four hours. Raw milk usually required five to six hours but occasionally required a longer period.

The time of digestion varied considerably in both the human subject and in calves. This variation is probably due to such factors as fatigue, individuality and state of health.

THE CORRELATION BETWEEN THE ORGANISMS FOUND MICROSCOPICALLY AND THE BACTERIOLOGICAL DETERIORATION OF BUTTER[1]

JOHN ALBERT NELSON

From the Department of Dairy Industry, Iowa State College

Good keeping quality is one of the cardinal virtues of butter that is properly made and is indispensable in the successful marketing of the product. Butter of poor keeping quality is a cause of heavy financial losses to creameries and butter merchants. To avoid financial loss, due to poor keeping quality, various tests have been devised to give a general idea of the sanitary conditions under which the butter was made, but none of these tests give any idea of the keeping quality. In order to determine whether or not it is possible to predict the keeping quality of butter with reasonable accuracy by a microscopic study of the flora and to develop a practical method for determining keeping quality and for studying the changes in flavor score and microflora in butter this work was undertaken.

Samples of butter of varying quality were collected in two-ounce, glass stoppered, sterile bottles from a large number of butter plants. When received the butter was scored and criticised for flavor and aroma by experienced judges. Microscopic slides were prepared from the samples by the method devised by Hammer and Nelson[2] and the samples were also plated on beef infusion agar and the plates incubated four days at 21°C. The butter samples were then placed in an incubator and held at 21°C. for seven days. At the end of the holding period, the samples were again scored and criticised for flavor and aroma, and microscopic slides again made.

It was found that holding the samples at 21°C. for seven days in glass-stoppered bottles protected from light seemed to reveal the defects that the butter would develop under ordinary conditions, and consequently this time and temperature of holding were adopted.

The keeping qualities of the samples were predicted by a study of the microorganisms on the original slides, the predictions being made before the samples were rescored. The predictions were based on the types and numbers of organisms found on the original slides. The types and numbers of rods present seemed to be an index to the keeping qualities. If no rods, or only a relatively few rods, were found the keeping quality was not questioned, especially if the rods were of the thick type. If many thin rods were present, the possibility of the butter keeping was greatly reduced, particularly when the thin rods were well stained, indicating that the organisms were alive. Clumps of well stained thin rods were almost a sure sign of deterioration. A very few well stained thin rods were generally sufficient to cause deterioration in unsalted butter, while salted butter seemed to require a larger number, due presumably to the inhibiting effect of salt. In general, micrococci and yeasts did not seem to have any detrimental effect

on the keeping quality, even when large increases took place, especially in unsalted butter.

The keeping quality was studied with 303 samples of commercial salted butter, 93 of commercial unsalted butter, and 53 of exhibition butter.

The keeping quality was correctly predicted from the original microscopic slides with 292 (96.4 per cent) of the 303 samples of commercial salted butter, with 74 (79.6 per cent) of the 93 samples of commercial unsalted butter, and with 45 (84.9 per cent) of the 53 samples of exhibition butter. Since unsalted butter deteriorates more readily than salted butter, it would be reasonable to expect that the keeping quality of unsalted butter would be more difficult to predict correctly than the keeping quality of salted butter. Due to the presence of a small amount of salt, exhibition butter should not deteriorate as readily as unsalted butter and, accordingly, it would also be reasonable to expect that the keeping quality of exhibition butter would not be as difficult to predict correctly as the keeping quality of unsalted butter.

From the results obtained, it appears that much can be learned about the keeping quality of butter by holding samples at 21°C. for seven days and comparing, microscopically, the microflora when received with the microflora after the holding period. By observing the morphologic types of organisms present on the microscopic slide made from a sample of butter before the holding period, the keeping quality can be fairly accurately predicted. From the same slide, the number of microorganisms in the butter can be estimated and a general idea as to the quality of the cream used can be obtained. Furthermore, by studying the types of organisms present on the slide an idea as to whether or not butter culture was employed in the manufacture of the butter can be had. By comparing the numbers and types of organisms found on the microscopic slide made after the holding period with the organisms found on the original slide, the increase or decrease in the numbers of organisms of the various morphologic types during the holding period can be estimated. The numbers and types of organisms on the slide will also indicate whether or not the butter was carefully made under sanitary conditions and, in case deterioration did take place, whether this deterioration was due to microorganisms or to some other cause.

The most prevalent defects encountered after the holding period in the samples studied were protein decomposition, cheesiness, and putrid. These defects developed in 10 per cent of the commercial salted samples, 25.8 per cent of the commercial unsalted samples, and 30.2 per cent of the samples of exhibition butter. The original microscopic slides made from these samples showed the presence of small thin rods, and the microscopic slides made from the deteriorated samples revealed enormous numbers of such rods, so that there was apparently extensive growth during the holding period. The plate counts did not indicate in any way that these samples would deteriorate.

The growth of microorganisms during the holding period did not always result in deterioration. Higher microscopic counts were found after the holding period than before in 59.7 per cent of the commercial salted samples, 89.2 per cent of the commercial unsalted samples, and 92.5 per cent of the samples of exhibition butter. The types of organisms which developed and predominated after the holding period seemed to be the deciding factor in whether or not deterioration took place. In no case did a sample show good keeping quality when small thin rods predominated in the microflora

of the butter after the seven-day holding period. Micrococci developed readily, especially in unsalted and exhibition butter held at 21°C., but they apparently did not have any influence on the keeping quality. This would be reasonable to expect when, in general, micrococci cause changes in milk only slowly. In nearly all cases where deterioration did take place, a large increase in the numbers of microorganisms was found. This would indicate that bacteriological deterioration is more prevalent than chemical detorioration of butter under the holding conditions used in the tests.

No correlation existed between the plate counts and the keeping qualities of the butter. Some samples with low plate counts kept poorly, and some samples with high plate counts kept well. Keeping quality did not seem to be so directly related to the numbers as to the types of microorganisms present in the original butter. The colonies found on the plates did not indicate the general types of organisms responsible for deterioration of the butter.

The flavor scores of the butter when received could not be correlated with the keeping quality. There were samples in the lower range of flavor scores that kept well, and others that kept poorly, and the same was true of the samples in the higher range of flavor scores. This indicated that the quality of the cream was probably not as important a factor in making butter of good keeping quality as the care exercised and the sanitary conditions under which the butter was made.

The changes in numbers of butter culture organisms in butter were studied, both by the plate and by the microscopic method, in eight samples of salted butter, and in eight samples of unsalted butter held at 21°C. The organisms did not develop to any extent in the salted butter, but did develop very well in the unsalted butter. It was also noted in comparing the appearance of the cells of the butter culture organisms in the salted butter with the appearance of the cells of the same culture in unsalted butter that the cells in the salted butter seemed to be shrivelled, and were stained a little deeper in color. This difference was probably due to the presence of salt.

The changes in the numbers of *S. lactis* and citric acid fermenting streptococci were studied both by the plate and by the microscopic method, in ten samples of salted butter and in ten samples of unsalted butter held at 21°C. These organisms also developed slowly, if at all, in the salted butter but developed very well in the unsalted butter.

The changes in numbers of microorganisms were studied microscopically in 18 samples of salted butter, and in 11 samples of unsalted butter held at about —20°C. for storage periods ranging from 150 to 171 days, after being held for seven days at 21°C. There was always a decrease in numbers of microorganisms, both in the salted and the unsalted butter, during the storage period. The microflora of the stored butter, as shown by the microscopic slides, appeared about the same as that of the butter before storage, but many of the cells were partly autolyzed.

THE MICROFLORA OF CHURNS AND ITS IMPORTANCE IN THE DETERIORATION OF BUTTER[1]

Harold Cecil Olson

From the Department of Dairy Industry, Iowa State College

Studies carried out on 27 churns in 24 Iowa creameries showed that the sanitary condition of the churns varied greatly and that few of them were in a satisfactory sanitary condition. The microflora of the churns with low bacterial counts usually included few types, chiefly members of the genus Bacillus, while the microflora of churns with high bacterial counts usually included many types, chiefly micrococci. The yeast and mold counts were much lower than the bacterial counts and were roughly proportional to them. The general sanitary condition of a plant was usually a better index to the cleanliness of the churn than the churn washing procedure reported by the plant manager.

Uniformly low bacterial, yeast and mold counts were secured on churns treated with the procedure normally used in the Iowa State College creamery. This consists of rinsing out the fat, filling the churn one-third to one-half full of water at 180°F. or higher, adding washing powder, revolving for 15 minutes and draining; the churn is then filled one-half full of water at about 200°F., revolved for about 20 minutes, drained and dried. The microflora of the normally washed churns included very few types, chiefly members of the genus Bacillus. The yeast and mold counts were commonly higher on churns that had stood a day or two after washing than on the freshly washed churns.

The treatment of normally washed churns with solutions of sodium hypochlorite, chlorinated lime or calcium hypochlorite resulted in significant reductions in the numbers of organisms in the churns; the concentrations of available chlorine used ranged from 56 to 122 ppm., the temperatures of the solutions from 70° to 139°F. and the periods of exposure from 5 to 45 minutes. The counts after treatment were all so low and the variations so small that no definite conclusions could be drawn as to the effect on the final counts of variations in concentrations of available chlorine, and in temperatures and periods of exposure; there was apparently less correlation between these factors and the count following treatment than between the counts before and after treatment. There were evidently no differences in the efficiencies of the three chlorine compounds used. In general, the decreases in available chlorine were higher when the temperatures were comparatively high and the periods of exposure comparatively long.

The treatment of a normally washed churn with saturated solutions of sodium chloride did not significantly reduce the numbers of organisms contained in the churn; there was evidence of certain salt tolerant types being carried into the churn by the sodium chloride solutions.

The treatment of highly contaminated churns with sodium hypochlorite solutions resulted in significant reductions in the numbers of organisms in the churns; the concentrations of available chlorine of the solutions ranged

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from 75 to 141 ppm., the temperatures from 70° to 142°F. and the periods
of exposure from 10 to 60 minutes. In general, high concentrations of avail-
able chlorine, high temperatures and long periods of exposure resulted in
the greatest efficiencies but the temperatures of the chlorine solutions ap-
parently had a greater influence in determining the efficiences than the avail-
able chlorine concentrations or periods of exposure. Many types of organ-
isms were usually present in the churns before treatment while after treat-
ment there were few types, chiefly members of the genus Bacillus. Yeasts
and molds were never detected in the chlorine solutions after exposure to
the churns while significant numbers of these organisms were often found
in the water used to rinse the churns after treatment; this suggests the
presence in the churns of certain infection foci which did not have sufficient
contact with the sterilizing medium.

On a highly contaminated churn a commercial chloramine preparation
was not as efficient, especially in the destruction of yeasts and molds, as was
sodium hypochlorite. The concentrations of available chlorine of the solu-
tions used ranged from 28 to 113 ppm., the temperatures from 135° to 192°F.
and the periods of exposure from 20 to 80 minutes. The chloramine solu-
tions were most efficient at high temperatures and they were much more
stable than the hypochlorite solutions; even at the excessively high tem-
peratures used the decreases in available chlorine were not great.

Hot water was effective in reducing the numbers of organisms in churns
to a very low figure when the temperature of the water was 180°F. or higher
and the periods of exposure 30 minutes or longer, but spore forming bacteria
were able to survive. With short exposures yeasts, molds and non-spore
forming bacteria were able to survive; this suggests that they were harbored
in more or less protected places to which the heat did not penetrate suf-
ficiently.

Sixty-one pure cultures of bacteria isolated from churns were inoculated
into cream just before churning. All caused some changes in unsalted but-
ter stored at 59°F., although with many the changes were not great. In
general, organisms common to clean churns (genus Bacillus types) were not
as detrimental to the keeping quality of butter as the types commonly found
in highly contaminated churns. Mixed cultures, each representative of the
flora of a churn, brought about more rapid and more extensive changes in
butter than did the pure cultures.

The detrimental influence of a contaminated churn on the keeping quality
of butter made in it was demonstrated as follows: Half of a batch of pas-
teurized cream was churned in a contaminated churn and the other half in
the same churn after it had been thoroughly cleaned. Samples of the salted
and unsalted butter from the contaminated and clean churns were stored at
various temperatures and their keeping qualities compared. Counts were
run on the samples of fresh unsalted butter and on the samples after stor-
age. The fresh butter churned in contaminated churns had a considerably
higher average plate count and a significantly higher microscopic count than
the butter churned in the clean churns. After storage at 45°F. for from 21
to 63 days the unsalted butter from the clean churns usually had a lower
plate count than the butter from the contaminated churns and after storage
at room temperature (about 70°F.) for seven days the average microscopic
counts on the salted and unsalted butter from the contaminated churns were
higher than those on the butter from the clean churns.

The salted butter kept well at both 32°F. and 45°F. and there were no

significant differences in the scores on the butter from the contaminated and from the clean churns. The unsalted butter deteriorated rapidly both at 32°F. and 45°F., and the deterioration was most rapid at the higher temperature. The unsalted butter from the contaminated churns deteriorated more rapidly and more extensively than the butter from the clean churns, both at 32°F. and at 45°F. Rancidity was the most common flavor defect produced in butter from the contaminated churns, while cheesiness was most common in butter from the clean churns.

The possibility of the creamery air as a source of contamination of churns was demonstrated by exposing sterile malt agar and beef infusion agar plates to the creamery air and to the air within churns. Considerable number of organisms were found to fall on the plates and the numbers of bacteria were far greater than the numbers of yeasts and molds. The numbers of organisms falling into the churns were markedly decreased by covering the door openings with muslin.

THE COMPARATIVE CALCIUM AND PHOSPHORUS RETENTION OF PIGS FED RATIONS SUPPLEMENTED WITH LIMESTONE, BONE MEAL, AND "DICAPHO"[1]

John Melville Ramsbottom

From the Department of Animal Husbandry, Iowa State College

The purpose of the research herein reported, was to obtain information on the relative efficacy of ground limestone, steamed bone meal and Dicapho (a commercial di-calcium phosphate) as calcium supplements to rations for growing and fattening pigs. This work was conducted in two parts. Part I involved calcium and phosphorus metabolism studies, while Part II was concerned with the more practical phases, namely, the record of gains in liveweight and feed required per 100 pounds gain in liveweight.

PART I

Data were collected in metabolism experimentation, which involved 15 growing barrows ranging in initial weight from 50 to 230 pounds. This phase of the research included four metabolism trials, each of which consisted of two, three, or four metabolism periods 10 to 14 days in length. A series of consecutive tests made on the same group of pigs constituted a trial, while each test in a trial was termed a period and constituted a specific comparison of rations. The only exception was in the case of the check periods in which all pigs were compared in regard to individual variation in the metabolism of calcium and phosphorus.

Trials I, II, and III were designed to determine the efficacy of ground limestone, steamed bone meal and Dicapho when fed as calcium supplements, at low and high levels of intake, to a basal ration deficient in calcium. In an effort to make conditions even more stringent thereby increasing the possibility of showing differences which might exist in the utilization of these calcium compounds, vitamin D additions were purposely omitted from the ration. The ingredients of the basal ration as combined quite adequately supplied all nutrients necessary for growth except calcium and vitamin D. Trial IV was conducted with four uniform barrows withdrawn from four lots in the feed lot experiment reported in Part II to follow.

The experimental animals were purbred Poland Chinas with the exception of those used in Trial IV, which were crossbred. The metabolism crates employed were similar in construction, although somewhat smaller than those used by Forbes (3). The low calcium basal rations fed in Trial I, II, and III were composed of the following feeds: Ground yellow corn, soybean oilmeal, blood flour and salt (Na Cl). These basal rations contained from 0.05 to 0.1 per cent of calcium depending upon the proportion of the ingredients. The proportion of each constituent used was determined according to a recommended feeding standard (4). Ground limestone, steamed bone meal and Dicapho were added to the basal ration in amounts to supply an equivalent intake of calcium from each supplement. All constituents of

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the rations were finely ground and thoroughly mixed with the calcium supplements, which previously had been pulverized so that they would pass through a 200-mesh per inch sieve. The feces excreted by each pig during each metabolism period were collected daily and the composite preserved in 0.2 per cent formalin solution. At the end of each period representative composite samples were taken and prepared for chemical analysis. Composites of urine and wash water were also prepared for each pig during each period and preserved in thymolchloroform and hydrochloric acid.

The calcium in the feed, feces and urine was determined by McCrudden's Method (5) using the gravimetric alternative. The phosphorus in the ration and in the excreta was determined gravimetrically by the standard molybdate magnesium mixture method (1). All chemical analyses were conducted in triplicate.

The experimental results obtained show that when equivalent amounts of calcium as present in ground limestone, steamed bone meal and Dicapho were fed as supplements at low and high levels of intake to a low calcium basal ration, the retention of calcium and phosphorus by all these pigs was similar, except the one which received the high level of limestone supplementation. In the case of this exception, when the amount of the phosphorus in the limestone supplemented ration was increased by the use of a neutral mixture of mono- and di-sodium phosphate to an amount similar to that found in the bone meal supplemented ration, the pig's retention of calcium and phosphorus improved. Apparently hog rations having a Ca:P ratio as wide as 2.13:1 and at the same time supplying minimum quantities of antirachitic and phosphorus are unsatisfactory for best results. Rations with calcium to phosphorus ratios ranging from 0.6:1 to 1.6:1 gave satisfactory results. Bone analyses were made on the femurs and humeri of the four pigs used in Trial IV. The data revealed very small differences in the total ash, calcium and phosphorus composition of the bones of the pigs which received ground limestone, steamed bone meal and Dicapho. The femurs and humeri of the check pig, which had received only the low-calcium basal ration, were abnormally low in ash, calcium, and phosphorus.

PART II

A feed lot experiment was conducted simultaneously with the metabolism experiment. Eighty uniform pigs, 112 days old and averaging 88 pounds in weight, were used. These pigs were divided into eight lots of 10 pigs each, four lots formed Series I and the remaining four, Series II. Series II served as a check on Series I. As each lot of pigs reached an average weight of 225 pounds per pig, the lot was terminated. During the experiment one lot in each series was fed a finely ground check ration composed of corn, tankage, linseed oilmeal, alfalfa meal and salt (Na Cl). The remaining three lots in each series were fed the same check ration supplemented with equivalent amounts of calcium furnished by ground limestone, steamed bone meal, and Dicapho respectively.

Gains in liveweight and feed requirements per unit of gain were observed. The daily gains made by the pigs in each lot in Series II checked with those in Series I so that the largest difference in average daily gains per pig between lots was 0.1 pound. In reference to the statistical significance of a difference of 0.1 pound, it has been the experience of the Iowa Agricultural Experiment Station that differences up to 0.14 pound may be expected between pigs receiving the same treatment. One can conclude with consider-

able assurance, therefore, that these rations were all similar in their capacity to promote gain in liveweight. Data on feed consumption per 100 pounds gain in weight, show that the largest mean difference between lots receiving different rations was 11.41 pounds. The standard deviation of this mean difference was 5.66 pounds. The mean difference should be at least 4.3 times larger than its standard deviation (when there are but two degrees of freedom) to be significant (2). It is evident, therefore, that the differences in feed consumption per unit of weight between these lots of pigs were statistically non-significant. Calcium and phosphorus metabolism data collected from a trial which was conducted with representative barrows taken from Series II confirm these feed lot observations.

CONCLUSION

The results obtained in these experiments show that limestone, bone meal, and Dicapho are utilized by pigs as calcium supplements with equal efficiency, except when the calcium-phosphorus relationship of the ration is upset, as is possible when limestone is added in large amounts as a supplement.

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ORGANOMETALLIC COMPOUNDS OF GROUP II[1]

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In the study of the mechanism of certain reactions of organomagnesium halides it is not always possible to replace the –MgX group in the intermediate compound by other groups. Accordingly the organometallic compounds of calcium, strontium, barium, and beryllium were studied to determine whether such replacements could be more readily accomplished by the substitution of another metal for the magnesium.

I. ORGANOCALCIUM IODIDES

Beckmann[2] has made the only extensive study of organocalcium iodides. These compounds can be made by a technic similar to that used for the preparation of organomagnesium halides but reaction between calcium and organic iodide is more difficult to initiate, it is slower, and gives poorer yields. Only a limited number of RX compounds, namely ethyl iodide, n-butyl iodide, n-octyl iodide, and iodobenzene, were found to form organocalcium iodides. Ethyl bromide, iso-propyl iodide, tert.-butyl iodide, benzyl bromide, and benzyl iodide failed to react with calcium. The presence of organocalicum iodide was proved by the formation of typical derivatives and by a positive color test with Michler's ketone described by Gilman and Schulze[3].

During the formation of organocalcium iodides a voluminous white solid forms, this, contrary to Beckmann, was shown to be calcium iodide dietherate, $CaI_2 2(C_2H_5)_2O$. Apparently the main reaction is coupling of the alkyl groups. In the reaction between ethyl iodide and calcium a positive color test was obtained but the amount of ethycalcium iodide was insufficient to form the expected anilide with phenylisocyanate. The reaction between n-butyl iodide and calcium formed much calcium iodide dietherate, a trace of butane, and 29 per cent n-octane. The formation of n-butylcalcium iodide was proved by the formation of n-valeryl-α-naphthalide with α-naphthylisocyanate and by a positive color test. A positive color test was obtained with the product made by shaking calcium, n-octyl iodide, and ether in a sealed tube for 24 hours. Much calcium iodide dietherate was formed and 17.8 per cent hexadecane, $C_{16}H_{34}$, was isolated.

Phenylcalcium iodide seemed to be formed in better yield than other organocalcium iodides. It reacted with phenylisocyanate to form benzanilide. The intermediate product of this reaction failed to react with diethyl sulfate, therefore it was not possible to prove the mechanism of this reaction. Phenylcalcium iodide reacted incompletely with benzoyl chloride, the reaction product still gave a positive color test and had a strong odor of benzoyl chloride after 24 hours. The positive color test may be of little significance here for it was subsequently shown that some compounds, in-

[1] Original Thesis submitted December, 1927.

[2] Beckmann, Ber., 38, 904 (1905).

[3] Gilman and Schulze, J. Am. Chem. Soc., 447: 2002 (1925).

cluding acid halides, interfere with the color test.   About one per cent tri-
phenyl carbinol was formed in this reaction.

II. ORGANOSTRONTIUM HALIDES

In this study attempts were made to bring about reaction between ethyl
iodide or iodobenzene with metallic strontium in the presence of ether.
Small sealed tubes were used as reaction vessels.   Several varieties of stron-
tium were tried, including a sample of strontium amalgam; two samples of
electrolytic strontium; and a sample of sublimed strontium of high purity.
Iodine, or a mixture of mercuric chloride and iodine, were used as catalysts.
Temperature was varied from room temperature to 225°.   The tubes were
shaken for various lengths of time and allowed to stand for periods up to
one year.   The color test with Michler's ketone was used to test for the
formation of organostrontium halide.   In no case was there any evidence
that the desired reaction had taken place.

III. ORGANOBARIUM HALIDES

Attempts were made to prepare organobarium halides by methods similar
to those already described for strontium.   Samples of barium amalgam,
domestic electrolytic barium, and sublimed barium of high purity failed to
react with ethyl iodide or iodobenzene under a variety of conditions.   A
sample of foreign electrolytic barium reacted with iodobenzene to give a
positive color test and several characteristic derivatives.   However, this
sample, as well as the organometallic derivative, was shown to contain most-
ly calcium and only traces of barium.   In view of the results obtained it is
apparent that the desired organobarium halides may not have been obtained
in this study.

IV. CALCIUM, STRONTIUM, AND BARIUM DIALKYLS AND DIARYLS

Failure to obtain organometallic halides of strontium and barium led to
attempts to prepare the dialkyls and diaryls of the alkaline earth metals.
Various samples of calcium, strontium, and barium were treated in sealed
tubes with mercury diethyl, mercury di-n-butyl, mercury diphenyl, and
mercury di-p-tolyl.   These reactions were allowed to proceed at room tem-
perature to 225° for several hours to several weeks.   In spite of slight visual
evidence of reaction in a few cases the products in no case gave a color test
with Michler's ketone.   It was therefore apparent that the desired organo-
metallic compounds had not been formed.

V. ORGANOBERYLLIUM HALIDES

Several unsuccessful attempts have been made to prepare organoberyl-
lium halides.[4]   Durand[5] claimed to have prepared methylberyllium iodide
but his claims could not be substantiated by our study.   Methylberyllium
iodide was first prepared by us by heating a mixture of beryllium, methyl
iodide, ether, and a trace of mercuric chloride in a sealed tube at 80° to 90°.
In a similar manner we prepared ethylberyllium iodide, n-butylberyllium
iodide, phenylberyllium iodide, and ethylberyllium bromide.

The formation of organoberyllium halides does not take place below 80°
or 90°.   Phenylberyllium iodide is preferably prepared at 110° to 150°.

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4 Gilman, J. Am. Chem. Soc., 45: 2693 (1923).

5 Durand, Compt. rend., 182: 1162 (1926).

Catalysts for the reaction, in order of effectiveness, are: mercuric chloride, beryllium chloride, a mixture of mercury and iodine, iodine, and bromine. An alloy or beryllium and copper, activated with iodine, was not effective. Ethyl ether was the usual solvent, however, it is not essential since methylberyllium iodide was prepared by heating a mixture of beryllium, mercuric chloride, and a large excess of methyl iodide in a sealed tube.

Water decomposes organoberyllium halides with formation of the corresponding hydrocarbons. They react slowly with Michler's ketone to give a positive color test and rapidly if heated. Ethereal solutions do not fume in the air but the residues do when the ether is evaporated and heating is continued. Beryllium dialkyls are formed in this process by the following reaction:

$$2 \text{ RBeX} \longleftrightarrow \text{BeR}_2 + \text{BeX}_2$$

Carbon dioxide does not react with these compounds. Phenylisocynanate reacts to form the corresponding anilides. In general, the organoberyllium halides appear to be less reactive than beryllium dialkyls or the corresponding organomagnesium compounds.

VI. BERYLLIUM DIALKYLS

Cahours[6] claimed to have obtained beryllium diethyl by reaction of beryllium with ethyl iodide or mercury diethyl in sealed tubes at elevated temperatures. Inasmuch as he incorrectly described its physical and chemical properties it is quite probable that he did not obtain this compound. Lavroff[7] probably obtained beryllium dimethyl by reaction of beryllium with mercury dimethyl. Krause and Wendt[8] state that beryllium dialkyls may be prepared by the reaction between beryllium chloride and an excess of Grignard reagent.

We made several unsuccessful attempts to prepare beryllium diethyl and beryllium di-n-butyl by reaction of beryllium with pure mercury dialkyls under a variety of conditions. We succeeded in obtaining beryllium dimethyl by reaction of the metal with mercury dimethyl that contained a trace of methylmercury iodide. Beryllium diphenyl and beryllium di-p-tolyl were prepared by heating the metal with the corresponding mercury aryls with a trace of mercuric chloride in sealed tubes at 225° for six hours. It is possible to prepare beryllium alkyls from alkylberyllium halides, as shown by the previous study. However, the most convenient method is by the reaction of anhydrous beryllium chloride with the appropriate Grignard reagent.

Beryllium dimethyl, beryllium diethyl, and beryllium di-n-butyl were prepared by this method. An ethereal solution of anhydrous beryllium chloride was added to the Grignard reagent. The product was isolated and purified by a process of ether vapor distillation, advantage being taken of the volatility of beryllium dialkyls with ether vapor. Since the beryllium dialkyls are very sensitive to oxygen or moisture it was necessary to conduct all operations in an atmosphere of pure, dry hydrogen or nitrogen.

Beryllium dimethyl was obtained in the form of white needles when an ethereal solution was evaporated in an inert atmosphere. It is also deposited

6 Cahours, Ann. Chim. Phys., (3) 58: 22 (1860); Comp. rend., 76: 1383 (1873).

7 Lavroff, J. Russ. Phys. Chem. Soc., 16: 93 (1884); Bull. soc. chim., (2) 41: 548 (1884).

8 Krause and Wendt, Ber. 56: 467 (1923) footnote 2.

in this form when it sublimes, without melting, at about 200°. Analysis for beryllium, and the amount of methane liberated by hydrolysis, proved its composition to be $Be(CH_3)_2$. Beryllium diethyl melts at —13° to —11° and boils at 93-95°/4 mm., 110°/15 mm., and 180-240° at atmospheric pressure. Beryllium di-n-butyl boils at 170°/25 mm.

Beryllium dimethyl and beryllium diethyl are spontaneously inflammable in the air. Beryllium di-n-butyl reacts with air, with evolution of heat, to form beryllium butylate. Beryllium dialkyls react violently with water to form the corresponding hydrocarbons and beryllium hydroxide. Pure beryllium dimethyl inflames in carbon dioxide and in ethereal solution it forms acetic acid by reaction with carbon dioxide. Triethyl carbinol is formed by the reaction between carbon dioxide and an ethereal solution of beryllium diethyl. Phenylisocyanate reacts with violence with ether solutions of beryllium dialkyls to form the expected anilides. An instantaneous positive color test is obtained with Michler's ketone. Benzophenone reacts with beryllium dimethyl to give diphenylmethylcarbinol; beryllium diethyl, on the other hand, reduces benzophenone to benzhydrol. Beryllium dimethyl yields dimehtylphenylcarbinol with benzoyl chloride. Methylberyllium iodide is formed when beryllium dimethyl is treated with one equivalent of iodine. Beryllium diethyl and beryllium chloride form ethylberyllium chloride. The following equilibrium is probable:

$$BeR_2 + BeX_2 \longleftrightarrow 2\ RBeX$$

In general, beryllium dialkyls are at least equal in reactivity to Grignard reagents and apparently more reactive than alkyberyllium halides.

VII. ORGANOMETALLIC ANTI-KNOCK COMPOUNDS

The preparation of tri-p-bromophenylstibine and tri-p-dimethylaminophenylstibine was undertaken in connection with studies of organometallic anti-knock compounds. Tri-p-bromophenylstibine was prepared in 90 per cent yield by treating an ether solution of freshly distilled antimony trichloride with an excess of p-bromophenylmagnesium bromide. The product was a light yellow, transparent solid that refused to crystallize and therefore could not be completely purified. Several unsuccessful attempts were made to prepare tri-p-dimethylaminophenylstibine by the Grignard reaction and by condensation of dimethylaniline with antimony trichloride. The products of these reactions were dark, amorphous tars.

ORGANOLEAD COMPOUNDS[1]

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This thesis has for its purpose the consideration of two general types of reactions characteristic of organolead compounds. The first reaction concerns the preferential cleavage of carbon-lead linkages by hydrogen chloride in a study of the lability or negativity of radicals; the second deals with the introduction of water soluble, functional groups into organolead compounds.

(A). In the action of hydrogen chloride on an unsymmetrical organo-lead compound of either the R_3PbR' or R_2PbR_2' type the more negative or labile R' group is split off in preference to the less labile R group. Thus by verying the R and R' groups in a lead compound a complete series of radicals in the order of ease of cleavage can be formed; this series is at the same time a negativity or lability series of radicals and corresponds to a similar series obtained by the cleavage of either organomercury or organotin compounds.

By means of this cleavage reaction it has been shown that the increasing lability or negativity of some aryl radicals is as follows: phenyl, 2-thienyl, 2-furyl. Likewise, observations concerning the cleavage of phenyl-allyl-lead compound shows that the allyl group is apparently more negative than the phenyl group.

With this abnormal behavior of the allyl group in mind and in view of the fact that phenyl, thienyl and furyl ardicals contain a certain kind of unsaturation, a number of organolead compounds containing aliphatic unsaturated groups were cleaved in order to ascertain what influence unsaturation plays in the negativity or lability of radicals.

Triphenyl-allyl-lead $((C_6H_5)_3PbCH_2CH=CH_2)$, triphenyl-*beta*-styryl-lead $((C_6H_5)_3PbCH = CHC_6H_5)$ and triphenyl-(buten-3-yl)-lead $((C_6H_5)_3PbCH_2CH_2CH=CH_2)$ were split with hydrogen chloride and the results show the decreasing order of lability of these radicals to be: (allyl, *beta*-styryl), phenyl and buten-3-yl.

The results of cleavage indicate that the position of the double bond is the controlling factor in the lability of unsaturated radicals; the *beta*-styryl and the allyl radicals containing a double bond in the one and two position from the lead-carbon linkage, respectively, were more negative than phenyl while the buten-3-yl radical with the double bond in the three position is less negative. Not only the cleavage reaction but many other reactions also show the importance of the position of the double bond in the chemical and physiological behavior of these compounds.

The cleavage of triphenyl-allyl-lead and triphenyl-*beta*-styryl-lead gave tri- and di-phenyl-lead chlorides which were recovered almost quantitatively and identified by melting points and by conversion to tetraphenyl-lead with phenylmagnesium bromide. The propylene and styrene also resulting from cleavage were recovered and identified by their physical constants and in the case of propylene by conversion to di-bromopropane.

The abnormal cleavage of allyl and *beta*-styryl radicals does not extend to the buten-3-yl radical since triphenyl-(buten-3-yl)-lead yields benzene, diphenyl-butenyl-lead chloride and a mixture of lead chloride and phenyl-butenyl-lead dichloride. The benzene was identified as m-dinitro-benzene, and the diphenyl-butenyl-lead chloride was converted to triphenyl-butenyl-lead.

The cleavage of a different type of compound, diphenyl-di-biphenyl-lead $((C_6H_5)_2Pb(C_6H_4.C_6H_5)_2)$, did not give a smooth scission to one kind of radical, probably because of the quite similar labilities of phenyl and biphenyl radicals. The isolation and identification of diphenyl-lead dichloride and of diphenyl indicated that cleavage proceeds by at least two simultaneous reactions.

The preparation and properties of the hitherto unknown triphenyl-*beta*-styryl-lead, triphenyl-butenyl-3-yl-lead and diphenyl-di-biphenyl-lead are described. Buten-3-yl-magnesium halide was prepared for the first time from the corresponding unsaturated halide, and the yield is essentially quantitative.

(B). The introduction of functional groups into organolead compounds was attempted in two ways: namely, the coupling of organolead halides with substituted halogen compounds and by rearrangement of some diazonium complexes of di- and tetra-valent lead chlorides in the presence of copper-bronze and other metals. The diazonium complexes of plumbous chloride were prepared for the first time.

Neither method gave a substituted organolead compound although tetraphenyl-lead was obtained in 22 per cent yield by the coupling of triphenyl-lead chloride with chlorobenzene in the presence of sodium. However, magnesium reacted with mixtures of organolead halides and *alpha*-halogen esters, but no definite coupling products were obtained. In the case of triethyl-lead bromide, magnesium reacted with this compound itself to give ethylmagnesium bromide and tetraethyl-lead. The mechanism of this unusual reaction of magnesium on another organometallic halide to give a Grignard reagent indicates the intermediate formation of unstable (triethyl-lead)-magnesium bromide.

The reaction of phenylmagnesium bromide on lead chloride gave increased yields of tetraphenyl-lead and the mechanism of this reaction is discussed in relation to the appreciable amount of triphenyl-lead bromide obtained.

Triphenyl-lead bromide, triethyl-lead bromide and diethyl-lead dibromide were prepared from the tetra-substituted organolead compounds and hydrogen bromide. Triphenyl-p-anisyl-lead was also prepared and its properties described for the first time.

THE METABOLISM OF SOME NITROGEN-FIXING CLOSTRIDIA[1]

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Many of the soils of Iowa are too acid to support the growth of the aerobic nitrogen-fixing bacteria of the genus Azotobacter. It has been found, however, that some nitrogen is fixed in these acid soils. Since the anaerobic nitrogen-fixing bacteria of the genus Clostridium have been found active in soils with a pH well below 6.0, it was thought that these organisms might be responsible for the fixation of nitrogen. Experiments have been conducted, therefore, to study the anaerobic nitrogen-fixing Clostridia which live in those acid soils.

The experimental work was divided into four parts. First, it was necessary to develop satisfactory anaerobic culture methods, both for the isolation of pure cultures of the anaerobic nitrogen-fixers from the soil and also for the handling of cultures during nitrogen-fixation tests. Second, the determination of the reaction requirements of the bacteria for maximum nitrogen-fixation. Third, a study of the nitrogen metabolism of pure and mixed cultures of nitrogen-fixing anaerobes in order to determine the forms of nitrogen represented in "fixed" nitrogen and the processes accompanying nitrogen fixation. Fourth, the determination of the rate and extent of carbon dioxide prdouction as influenced by varying sources of nitrogen in the medium with calcium carbonate or calcium chloride.

The results obtained in this investigation may be summarized as follows:

Satisfactory methods were developed for isolating pure cultures of the anaerobic nitrogen-fixing bacteria from the soil. Deep tubes of nitrogen-free agar medium were inoculated with a pasteurized soil extract and colonies appearing deep in the medium were picked and tested for their nitrogen-fixing capacity. Some of the most vigorously growing organisms were selected for experimental purposes. It was found that large numbers of anaerobic nitrogen-fixing bacteria were present in Grundy silt loam having a pH of 5.3, and in Tama silt loam, also having a pH of 5.3.

Results were obtained in tests with samples taken from variously limed plots on these two soil types which indicated that varying applications of lime had no effect upon the numbers of anaerobes or upon their ability to fix nitrogen in soil-solution cultures in the presence of nitrogen gas. A stimulating effect was observed, however, in soil taken from a plot on Tama silt loam which had received sufficient lime to meet the lime requirement and in addition, 100 pounds of 20 per cent superphosphate per acre.

In soil-solution cultures and in pure cultures incubated in an atmosphere of nitrogen gas it was found that the arbitrary incubation period of 3 weeks was probably sufficient to measure the maximum amount of fixation.

The effect of the initial pH of the medium upon nitrogen fixation was studied using soil-solution cultures incubated under anaerobic conditions. The initial pH of the medium apparently had very little effect, since in nitrogen-free media having initial pH values ranging from 6.5 to 9.5 there

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[1] Original Thesis submitted June, 1933.

were from 4.0 to 4.3 mgm. of nitrogen fixed per 50 cc. of medium. In 50 cc. of a similar medium having an initial pH of 5.0 there were 3.2 mgm. fixed. No consistent relationship was noted between the pH of the medium and the amounts of nitrogen fixed over the pH range studied, but a direct correlation was observed between changes in pH and glucose utilization. With all the media having initial pH values from 5.0 to 9.5 the reaction had been brought to a pH of approximately 5.0 within 5 days. It was concluded that the optimum pH for growth and fixation of nitrogen by the soil anaerobes extended over a wide range.

In the nitrogen metabolism studies both fixed cultures and pure cultures of anaerobes were used. The mixed cultures were obtained by inoculating soil into sterile liquid medium and pasteurizing the mixture. The suspension obtained after the solids settled out was used for the tests. One of the pure cultures of anaerobes, culture 5, was *Clostridium butyricum*, and the other, culture 4, was not identified. Both cultures were isolated from Tama silt loam. The medium used was Winogradsky's nitrogen-free liquid medium containing calcium carbonate or calcium chloride. In these metabolism studies quantitative determinations for total nitrogen, ammonia and amino nitrogen, glucose utilization, total acid, and in some cases volatile acids and pH, were made at 5-day intervals over a period of 20 or 25 days.

Comparatively large amounts of nitrogen were fixed in the mixed cultures in both media but the highest results were obtained when the calcium was present in the carbonate form. In the calcium chloride medium larger amounts of amino nitrogen and ammonia were produced than in the carbonate medium. Large amounts of these two forms of nitrogen were never present, however. Larger amounts of acid were present in the medium containing the calcium chloride than in that containing the carbonate.

The two pure cultures reacted somewhat similarly when growing in the same medium. In the calcium chloride medium culture 5 was more efficient in fixing nitrogen. A marked stimulating effect was noted in both cultures when calcium carbonate was used in the medium instead of calcium chloride. The effect was evidenced in increased nitrogen fixation and also in glucose utilization. The fixed nitrogen could not be accounted for either as amino nitrogen or as ammonia, since only small amounts were found present at any time. Upon applying qualitative tests for nitrites and nitrates to the cultures it was found that both these forms of nitrogen were present in the two anaerobic cultures growing in the medium when the carbonate was present.

Further metabolism studies were made growing culture 5, *Clostridium butyricum,* in media containing peptone, ammonium sulfate and sodium nitrate, and all containing calcium carbonate. The sources of nitrogen in the medium stimulated the utilization of glucose, the most pronounced effect being observed in the sodium nitrate medium. At the end of 25 days all the glucose in the 2 per cent solution in all the media had been utilized. Only negligible amounts of nitrogen were fixed in the medium containing peptone or ammonium sulfate. Small amounts were found fixed in the sodium nitrate medium. Ammonium sulfate stimulated the production of amino nitrogen. Steady increases were observed during the 25 days of incubation. In this medium approximately 5 mgm. of ammonia, which were present in 100 cc. of the medium at the beginning of incubation, entirely disappeared by the fifth day. Close correlations were observed between the amount of acids present and glucose utilization in all the media. Apparently the calcium carbonate did not neutralize the acid as soon as it was

formed. However, marked decreases in acidity were observed toward the end of the incubation period.

The comparative effects of nitrogen-free medium and media containing varying sources of combined nitrogen with calcium carbonate or calcium chloride in nitrogen gas and in air upon the production of carbon dioxide by *Clostridium butyricum* were studied. The Warburg micromanometric technic was employed in this test. The amounts of carbon dioxide produced in the various media were about the same when the organisms were grown in the nitrogen gas or in air. It is probable that no pronounced detrimental effect due to air could be observed because a liquid medium was used and constant evolution of carbon dioxide would tend to hinder the absorption of the oxygen of the air by the medium. When calcium carbonate was present large amounts of carbon dioxide were produced. In some tests twice as much was produced in peptone medium as in nitrogen-free or sodium nitrate medium. When calcium carbonate was replaced with calcium chloride in the various media only very small amounts of carbon dioxide were produced.

Results of further studies indicated that the larger part of the carbon dioxide produced by *Clostridium butyricum* came from the breakdown of the glucose molecule, 1 mole of glucose yielding 1 mole of carbon dioxide. The neutralizing effect of the carbonate upon the acid would probably account for a small amount.

The beneficial effect of calcium carbonate in the medium observed in most, of the experiments with anaerobic nitrogen fixers was probably due to its ability to neutralize the acids produced in the medium. It is also possible that the carbonate serves very effectively as an hydrogen acceptor in these anaerobic fermentations.

FURFURAL AND SOME OF ITS DERIVATIVES[1]

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The purpose of this thesis is to show, by means of a number of appropriate derivatives needed for future investigation in furan chemistry, the methods and technique best adapted to this field. Since nuclear substitution reactions are least amenable, they are given the most consideration. These are conveniently divided into sulfonations, nitrations, and halogenations.

Certain precautions are given for working with furan compounds. Positively substituted furans (with substituents like chloro, bromo, iodo, methyl, amino, and the like) are quite unstable toward acids, which must be avoided as much as possible in their reactions. This instability seems to be due to ring splitting. Negatively substituted furans (having substituents like nitro and carboxyl) are, conversely, more stable toward acids, but are proportionately less reactive. The nitrofurans are especially sensitive toward alkalis which completely decompose them, probably with ring splitting. Intermediate between these classifications are compounds like furfural and furylacryic acid. The ease of decarboxylation of the furoic acids is noted.

All furan compounds are relatively thermally unstable, the tendency being toward resinification. Hence high temperatures and in some cases, prolonged use of hot solvents are to be avoided. Since the resins or polymers are non-volatile, steam distillation is an important and frequently used process in furan technique. When furan compounds are stored for any length of time, low temperature, absence of light and absence of oxygen are recommended.

The sulfonation reactions attempted were entirely unsuccessful. These include sulfonation of furfural and certain furfural derivatives where the aldehyde group was blocked. The use of N-pyridinum sulfonic acid was found not to be successful for sulfonating furfural or furfural diacetate.

All the known nitrations of furan compounds are listed in a chronological table. The structure of the nitro compounds and the mechanism of nitration in acetic anhydride are considered. A mechanism involving direct addition of acetyl nitrate to the furan ring is suggested to supersede the prevailing mechanisms of ring splitting or 1,4- addition. Some attempted Beckmann rearrangements of furyl methyl ketoxime, intended to prove the position of the nitro group, were unsuccessful. In the hope that diazotization would prove the position of the nitro group to be *alpha-*, some of the nitro compounds were reduced to the corresponding amines. It was found that these amines would not form salts and would not diazotize. The nitro group in nitrosylvan was allocated with respect to the other nitrofurans by reduction of nitrofurfural via the Wolff reaction. Nitrosylvan was shown to be decidedly resistant to oxidation. Attempts to prepare *beta*-nitrofuran showed that *alpha*-bromo or iodo furans could not be nitrated in acetic anhydride. The inert nature of nitrofuran was shown by a prolonged attempt at bromination.

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[1] Original Thesis submitted July, 1932.

In proposed halogenation of any furan derivative it is necessary to predict the stability of the expected product. The stability and reactivity of some *alpha-* and a few *beta-*halogenated furans are therefore discussed. The mechanism of furfural diacetate bromination was educed by means of the addition compound obtained as a by-product in the reaction. When, 5-bromofurfural or 5-chlorofurfural was treated with phenylmagnesium bromide, the resulting carbinol lost hydrobromic acid spontaneously. A study of the resulting product on the basis of a 1,5-allylic rearrangement showed it was not 5-phenylfurfural. Its structure was not determined although a number of reactions giving contributory information were carried out. 5-Chlorofurfural was smoothly reduced to 5-chlorosylvan which was found to be quite stable. The same Wolff reaction applied to 5-bromofurfural led to ambiguous results. Although 5-chloro and 5-bromofurfuryl alcohol seem incapable of existence, reduction of 5-chlorofurfuraldoxime gave a very stable 5-chlorofurfuryl amine. When furfuryl chloride was treated with silver nitrite, no nuclear nitro compounds could be isolated. Rearrangement reactions with the Grignard reagent were not realized since furfuryl chloride would not react with ordinary magnesium, and activation of the metal gave only difurylethane. The brominated furylacrylic esters showed little tendency to lose substituted halogen. Even on reduction the nuclear bromine was not removed spontaneously.

The activity of nuclear halogenated furans toward magnesium shows some peculiar characteristics. Although 2-iodofuran reacted easily with magnesium, 2,5-diiodofuran required the reactivated metal and then gave only the mono-Grignard reagent; 3-iodofuran, on the other hand, would react with neither magnesium nor its activated modification. Comparative studies in method of preparation of the Grignard reagent show that the halogen in 3-iodofuran is less reactive than in chlorobenzene. Similar properties were shown by 3-bromofuran. The *beta-* halogenofurans were found to be much more stable than the corresponding *alpha-* derivatives.

THE PHYSICAL-CHEMICAL PROPERTIES OF ALCOHOL-GASOLINE BLENDS

III. THE A. S. T. M. DISTILLATION CURVES AND REID VAPOR PRESSURE

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Within the last few years, the A. S. T. M. distillation data have become one of the most commonly used specifications for motor fuel. These temperature specifications are changed to meet seasonal conditions to give the higher test gasoline of winter and the less volatile gasoline of summer. Aside from the anti-knock qualities, the distillation characteristics are also the major differences between the premium, regular and competitive grades of fuels sold at any one season.

The correlation of motor performance with the A. S. T. M. distillation curve for the fuel has resulted from the research work of many individuals. A summary and bibliography of this is given in the recent paper by Blair and Alden (1). While the automotive engineer and petroleum technologist are not in complete agreement as to what these specifications should be for the fuel to give maximum motor performance the following general statement is frequently given.

1. The temperature of distillation of the first 10 per cent of the fuel is a relative measure of its starting qualities. This fraction will also be a relative measure of the loss of fuel by evaporation during storage.

2. The temperature of distillation of the first 30 per cent of a fuel is a relative measure of the acceleration qualities of a fuel. This fraction also determines the performance of a cold motor on choke.

3. The temperature of distillation of the first 60 per cent of a fuel is a relative measure of the performance of the hot motor under driving conditions.

4. The temperature of distillation of the last 10 per cent of a fuel is a relative measure of the amount which will condense on the cylinder walls and cause crankcase dilution.

The distillation range for gasoline has changed greatly in the last twenty years. The gasolines of twenty years ago had a relatively low initial temperature and final temperature (70°–250°F.) The increased demand for gasoline has caused more of the higher fractions to be sold as gasoline with resulting increase in both the initial and final temperatures. The introduction of the cracking process has created greater supplies of the low boiling fractions with a resulting lowering of the initial temperature of present grade gasolines. The regular fuels available in the midwest have an initial temperature of about 100°F. and a final temperature of about 400°F., these temperatures varying somewhat with the season and variety of the gasoline.

DISTILLATION DATA FOR ALCOHOL BLENDS

Alcohol forms azeotropic mixtures with various hydrocarbons. It can accordingly be predicted that a lowering of the distillation temperature will be caused by the addition of alcohol to gasoline. This prediction has been verified by Ross and Ormandy (2) for British gasolines, by Schweitzer (3) for French gasolines, by Spausta (4) for Austrian gasolines and by Bureau of Standards (5) for American gasolines.

Samples of twenty different brands of gasoline sold commercially in the midwest have been examined in this laboratory. The data reported in table 1 for varying concentrations of alcohol in gasoline are typical of the results found for all the gasolines investigated. The data of Ross and Ormandy (2) have been plotted in figure 1 and the data of table 1 if plotted in the same manner give similar distillation curves. The data of Brown (6) are the only published data which are not in complete agreement with the above, a higher initial temperature being reported by him for the alcohol-gasoline mixtures than for the original gasoline. In using the A. S. T. M. method, the initial boiling point recorded is a function of the proportion of the low boiling constituents as well as their boiling point. This may account for the higher initial point reported by Brown. This increase in the initial temperature of distillation of the alcohol blends might also be obtained by using gasolines very poor in low boiling constituents, but it certainly is not characteristic of the commercial grades of fuels in this or in the foreign countries from which data are available.

Fig. 1. Comparison of the A. S. T. M. distillation curves for a premium gasoline, (C) a lower grade of gasoline, (A) and a 10 per cent alcohol blend with the latter gasoline (B). Data taken from Ross and Ormandy.

As pointed out above, the A. S. T. M. distillation data for a fuel can be used as a qualitative measure of the performance of the fuel in a motor. The data of table 1 have been plotted in figure 2 in such a manner as to emphasize the influence of the alcohol content of the fuel on the temperature of volatilization of the successive fractions. The temperature of volatilization of the 10 per cent, 30 per cent, 60 per cent and 90 per cent fractions are of particular interest; referring to these fractions as plotted in figure 2 it is seen:

1. That the initial temperature of distillation and the temperature of the first 10 per cent distilling are not appreciably changed until alcohol concentrations of 40 per cent or more are reached. So far as volatility of fuel is concerned there should be no appreciable difference in starting qualities of the blends containing 10 per cent or 20 per cent alcohol and that of the original gasoline. The easier starting qualities reported for the alcohol blends particularly in winter weather are probably due to the fact that alcohol forms explosive mixtures with air over a wider range of

proportions than does gasoline. It would also be concluded that the alcohol blends would show no greater loss in storage than would the original gasoline.

TABLE 1. *Influence of absolute alcohol concentration upon the A. S. T. M. distillation range of alcohol gasoline*
Gasoline dried over CaCl₂. Absolute alcohol dehydrated with CaO

Percentage distilled	Alcohol content of blend percentage by volume								
	Nil.	0.5	1.0	2.0	4.0	6.0	8.0	10.0	15.0
	°F	°F	°F	°F	°F	°F	°F	°F	°F
Initial	101	100	100	101	100	100	102	104	101
5	125	119	119	118	119	121	121	122	123
10	137	133	138	136	134	129	130	131	132
20	165	169	169	161	169	142	142	144	144
30	193	191	196	190	188	163	151	152	152
40	218	214	220	215	214	208	195	182	158
50	241	242	242	240	238	236	232	230	215
60	266	268	272	268	268	260	260	258	247
70	295	294	293	293	293	291	290	286	282
80	326	327	328	327	327	322	321	318	316
90	368	371	371	371	374	375	370	368	341
Final	400	401	398	398	400	398	400	401	394
Residue %	2.0	2.0	1.5	2.0	2.0	2.0	2.0	2.0	2.0
Recovery %	95	95	94	95	94	95	95	95	90
Bar. mm. Hg.	730	730	730	730	730	730	730	730	720
Room t. F.°	73	73	73	73	73	73	73	73	73

Table 1.   continued

Percentage distilled	Alcohol content of blend percentage by volume								
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100
	°F	°F	°F	°F	°F	°F	°F	°F	°F
Initial	103	100	104	106	108	138	145	150	173
5	123	125	130	138	140	148	154	169	174
10	133	134	138	140	154	162	168	171	174
20	145	150	160	165	165	167	171	172	174
30	154	163	165	167	169	170	172	173	174
40	159	167	167	169	171	171	173	174	174
50	163	169	169	171	172	172	173	174	174
60	233	180	171	172	173	173	173	174	174
70	271	266	239	173	174	174	174	174	174
80	306	300	295	284	176	175	174	174	174
90	330	338	342	325	336	176	175	174	174
Final	391	390	388	383	379	376	358	358	174
Residue %	2.0	1.0	1.0	0.8	0.8	0.5	0.5	0.2	0
Recovery %	97	97	98	98	97	98	98	98	98
Bar. mm. Hg.	720	733	736	733	736	736	736	730	730
Room t. F.°	73	73	90	73	90	90	90	90	90

2. That the temperature of volatilization of the first 30 per cent of the fuel is much lower for the alcohol blends than for the original gasoline. The greater volatility of this fraction undoubtedly accounts for the better acceleration of the alcohol blends particularly noticeable in cold weather. The data of Ross and Ormandy, figure 1, offer a direct comparison in this respect of a third grade gasoline, a 10 per cent alcohol blend with the same third grade gasoline and a premium fuel.

3.   That the temperature of volatilization of the first 60 per cent of the fuel is very slightly affected by 10 per cent alcohol and depressed approximately 30°F. by 20 per cent alcohol. In harmony with this fact, very little difference can be observed in the power output of the hot motor under road conditions when operating on the 10 per cent blend or the original gasoline. The general observation has been that motor operation is smoother on the blend than on the original gasoline.
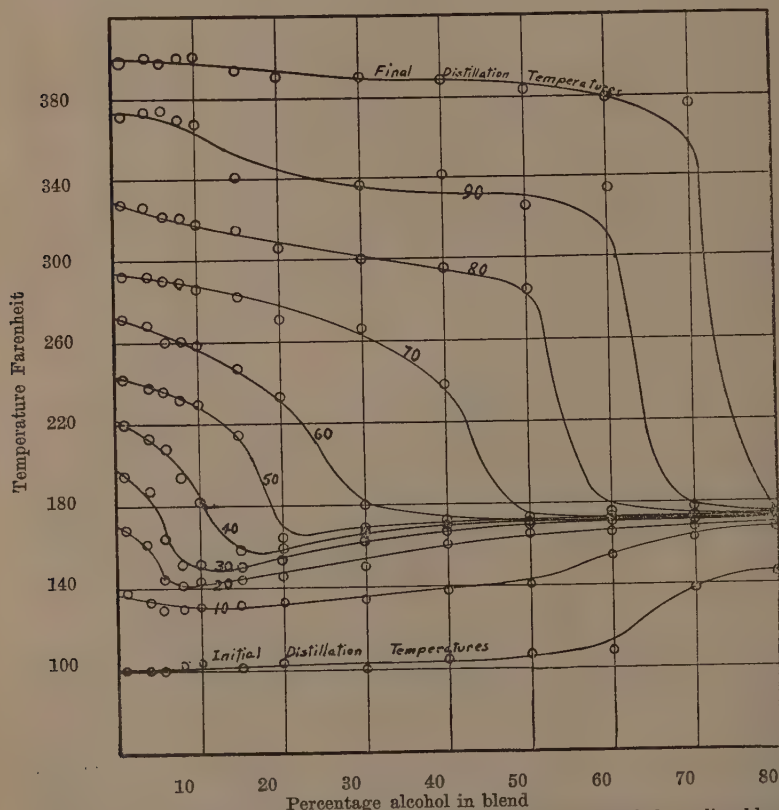
Fig. 2. The temperature of distillation of various fractions of alcohol-gasoline blends as a function of the alcohol concentration in the blend.

4.   That the temperature of volatilization of the last 10 per cent of the fuel is not affected by 10 per cent alcohol but is lowered by addition of the 20 per cent or more of alcohol. The decrease in oil dilution reported for the alcohol blends is probably due to better combustion and lower flame temperatures rather than to greater volatility of this fraction of the fuel.

The slight effect of water on the A. S. T. M. distillation data for 10 per cent alcohol–90 per cent gasoline fuel is shown in table 2. The A. S. T. M. distillation data for a 10 per cent butanol—90 per cent gasoline blend and for a 10 per cent acetone–90 per cent gasoline blend are also shown in table 2, as examples of blends not containing constant boiling mixtures.

TABLE 2. *Influence of absolute ethanol, aqueous ethanol, n-butanol and acetone upon distillation range*

Percentage distilled	Gasoline	10 per cent abs. ethanol 90 per cent gasoline	10 per cent abs. ethanol 0.4 per cent H_2O 89.6 per cent gasoline	10 per cent n-Butanol 90 per cent gasoline	10 per cent acetone 90 per cent gasoline
	°F	°F	°F	°F	°F
Initial	101	104	100	102	96
5	125	122	121	121	106
10	137	131	130	143	114
20	165	144	142	170	132
30	193	152	153	190	158
40	218	182	163	207	195
50	241	230	230	230	227
60	266	258	254	237	257
70	295	286	283	281	281
80	326	318	317	315	311
90	368	368	368	371	370
Final	400	401	397	393	396
Residue %	2.0	2.0	1.5	1.5	1.5
Recovery %	95	95	96	97	98
Bar. Hg. mm.	730	730	738	736	738
Room t. °F.	73	73	73	73	73

REID VAPOR PRESSURE AND VAPOR LOCK

The vapor pressures of gasoline with varying percentages of absolute alcohol are recorded in table 3. These have been measured by the A. S. T. M. method using dry equipment instead of wet. It will be noted that

TABLE 3. *Reid vapor pressure of alcohol blends*

Percentage Ethanol in blend	Reid vapor pressure (dry) lbs. sq. in.
0	7.5
4	7.5
8	7.8
10	8.4
15	8.7
20	8.6
30	8.7
50	6.9
100	Too small to measure

the addition of 10 per cent or 20 per cent alcohol to gasoline causes an increase in the vapor pressure of approximately one pound per square inch. This has been used (6) as an argument that the alcohol blends will show a greater tendency toward vapor lock than the original gasoline.

Vapor lock has been troublesome only in the last few years as a result of the tendency to market gasolines with larger quantities of low boiling constituents. While it is encountered in the more volatile gasolines it can-

not be directly correlated with the vapor pressure of the gasoline.   The recent work of Blair and Alden (1) would indicate that vapor lock is due almost entirely to the presence of small amounts of very low boiling constituents in the gasoline.   They have presented evidence to show that vapor lock in a particular motor could be correlated with the vapor equivalent of seventy-seven different gasolines of variable composition where the vapor equivalent was expressed as:

The estimated butane content of the fuel x 1.0
    ,,   ,,   pentane   ,,   ,,   ,,   ,, x 0.25
    ,,   ,,   hexane   ,,   ,,   ,,   ,, x 0.1

Referring to figure 2, it will be seen that the addition of alcohol to gasoline does not alter appreciably the volatility of these low boiling constituents which would distill over in the first 15 per cent of the fuel.   Attention should also be called to the fact that the high latent heat of alcohol would tend to decrease the tendency of the fuel to give vapor lock.

The data of table 4 would also support this conclusion.   These data report the loss in weight on exposure to air for varying lengths of time of

TABLE 4.   *Evaporation rates of alcohol blends in open beakers at 29°C.
in hood (no draft)*

Alcohol in blend	Evaporation loss percentage of original by weight					
Vol. pctg.	1 hour	3 hours	7 hours	17 hours	41 hours	65 hours
0	6.0	11.5	17.8	27.0	39.4	48.6
1	6.3	12.2	18.6	28.3	41.5	50.6
2	6.3	11.3	19.6	29.5	42.1	53.2
4	7.8	13.3	22.6	32.7	45.9	56.2
6	6.4	12.9	21.3	33.3	45.2	56.3
8	6.4	13.5	22.4	35.5	49.9	59.2
10	5.5	10.9	21.8	34.5	lost	—
15	5.4	11.6	19.7	32.1	56.7	65.9
20	5.3	11.3	19.4	32.3	53.6*	68.1
30	4.5	11.6	17.3	28.6	48.9*	66.4
50	3.5	8.3	14.3	24.1	41.5	61.6
100	0.7	2.3	4.5	10.2	24.6	42.0

NOTE: Separated into two phases.

a series of 150 cc. beakers containing 100 cc. of blends of varying percentages of alcohol in gasoline.   These data are shown graphically in figure 3. It will be observed that for the first three hours the loss in weight due to evaporation decreased slowly as the alcohol concentration in the blend increased.   After the more volatile fractions of the gasoline had vaporized (between 10 and 20 per cent) the rate of evaporation increased for those beakers containing alcohol, the 10 per cent and 20 per cent blends showing the maximum volatility after 17, 41, and 65 hours exposure.   This relationship would be expected from the distillation curves but it could not be anticipated from the Reid vapor pressure measurements.

Observations regarding the tendency of various fuels to cause vapor lock have been made on a car particularly sensitive to this difficulty.   While these observations have been qualitative in nature, they would indicate that vapor lock will not be encountered on blending alcohol with a gasoline which is itself free from this tendency.   The addition of alcohol to a gasoline which would cause vapor lock in this motor did not appear either to increase

or decrease this tendency. It is apparent that if such difficulty were encountered it could be eliminated by purchasing gasoline of lower volatility for use in preparing the alcohol blends.
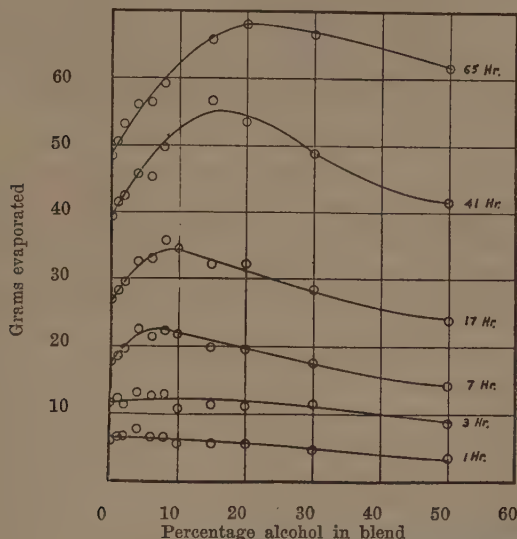
Fig. 3. The loss in weight by evaporation at room temperature from 100 gram samples of alcohol-gasoline blends at various periods of time as a function of the alcohol concentration in the blend.

STORAGE OF ALCOHOL BLENDS

It has been claimed that alcohol gasoline blends could not be stored under commercial conditions because of water absorption and evaporation.

TABLE 5. *Change in distillation range of alcohol blends during storage*

Percentage distilled	50,000 gallon tank		5500 gallon tank	
	Initial	After 66 days April 11-June 16	Initial	After 13 days April 28-May 11
Initial	95°F	104°F	113	110
10	130	137	140	140
20	143	143	149	148
30	139	150	158	157
40	—	160	213	212
50	168	212	237	238
60	—	247	259	257
70	—	298	—	—
80	—	334	—	—
90	378	380	—	—
Final	417	416	390	392
Residue %	1.5	1.5	1.4	1.2
Recovery %	96	97	97	96

Data are presented in table 5 for two separate storage tanks operating in regular commercial practice. The 50,000 gallon tank was under observation from the date the blend was prepared, April 11th, until emptied on June 16th. During this time alcohol-gasoline was withdrawn as needed to supply the trade. The blend still analyzed 10 per cent alcohol at the end of this time and was stable to –76°F. The distillation curve shows a loss of the more volatile fraction. The 5,500 gallon storage tank was also in regular commercial trade during the period of April 28th to May 11th. The changes were too slight to be observed in the distillation data or by change in turbidity temperature.

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THE PHYSICAL-CHEMICAL PROPERTIES OF ETHYL ALCOHOL GASOLINE SYSTEMS

IV. INFLUENCE OF ALCOHOL CONCENTRATION UPON SPECIFIC VOLUME, FLUIDITY, AIR-TO-FUEL RATIO, CALORIFIC VALUE, LATENT HEAT, AND FALL IN TEMPERATURE ON EVAPORATION

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As stated in the preceding papers of this series, it is the purpose of the researches here described to supply information on the physical-chemical properties of ethyl alcohol-gasoline blends which will be of value in the consideration of the proposal to utilize alcohol from agricultural products in motor fuel. In the first two papers of this series (4, 5) are given the results of studies on the water-holding capacity and water absorption of such blends and in the third paper (6) are given data on vapor pressure, distillation range and evaporation rates. In this paper there are presented data on specific volume, fluidity, correct air-to-fuel ratio, calorific value, latent heat, and fall in temperature on evaporation.

The blends were prepared with the same gasoline and alcohol used in the work previously described. The alcohol was dried over lime to a water content which could not be detected with potassium permanganate or anhydrous copper sulphate. The gasoline was dried over calcium chloride. The gasoline was a representative mid-continent grade purchased locally.

1. SPECIFIC VOLUME OF ETHYL ALCOHOL-GASOLINE SYSTEMS

The specific gravities were measured by means of a chainomatic Westphal balance. The data obtained for $25°/25°$ were calculated to $25°/4°$. The data so obtained are given in table 1.

There are also given values calculated on the assumption that the density is a linear function of composition. It will be noted that these values are greater than the experimental values, that is the system has undergone an expansion on mixing. From the differences between the calculated and experimental specific volumes it is seen that the expansion is dependent upon the concentration, being at a maximum at about 8-10 per cent of alcohol. The expansion amounts to 0.2-0.3 per cent for alcohol concentrations from 4-30 per cent of alcohol.

These results are in harmony with those of Balada (2) who observed the expansion and also the fact that the systems show a cooling on mixing. In order to test the latter point qualitatively, ethyl alcohol and gasoline were mixed in flasks at room temperature and the temperature of the mixture measured. These preliminary data are given in table 1. It is evident that the temperature fall is easily detected and is apparently at a maximum at the concentrations which show a maximum expansion. Data are not available for the exact calculation of the heat absorption accompanying the mixing of the alcohol and gasoline. While the amount of heat absorbed may be small, it is of interest to note that the heat content of the blend will be increased by the amount of heat absorbed, compared to the values ob-

tained by assuming a linear relationship of the heat contents of the pure substances.

The specific gravity of the fuel is of importance in carburetion since a large increase would cause a change in fuel level and in flow into the venturi. The data show the density of the 10 per cent alcohol-gasoline blend to be only 0.6 per cent greater than the gasoline used in making the blend. This is about 60 per cent of the increase to be expected without taking the expansion into consideration. This observed change in specific gravity of the 10 per cent blend corresponds to a difference of 1.2° Baumé, which is less than the variation in the specific gravity among various gasolines as shown by Ricardo (15). Evidently this slight increase is of no practical significance in carburation.

2. THE VISCOSITIES AND FLUIDITIES OF ETHYL ALCOHOL-GASOLINE SYSTEMS

The viscosities were measured by means of an Ostwald viscosimeter completely immersed in a water thermostat at 25°C. The values so obtained are given in table 2. The data were calculated to give the coefficients of viscosity and fluidities, making use of the densities of table 1. It

TABLE 1. *Densities and specific volumes of ethyl alcohol-gasoline systems*

Ethanol % by vol.[1]	Sp. G. 25°/4° exp.	Sp. G. 25°/4° calc.[2]	Sp. G. calc. minus Sp. G. obs	Specific volume exp.	Specific volume calc.[3]	Expansion per 100cc blend	Lowering in t°C. on mixing
0	0.7212	0.7212	0	1.3866	1.3866	0	0
1	0.7214	0.7219	0.0005	1.3863	1.3855	0.08	—
2	0.7217	0.7226	0.0009	1.3856	1.3843	0.13	—
4	0.7225	0.7239	0.0015	1.3841	1.3820	0.21	1.5
6	0.7236	0.7252	0.0016	1.3820	1.3797	0.23	—
8	0.7246	0.7265	0.0019	1.3800	1.3775	0.25	—
10	0.7257	0.7278	0.0021	1.3780	1.3752	0.27	2.5
15	0.7292	0.7310	0.0018	1.3714	1.3695	0.19	—
20	0.7323	0.7342	0.0019	1.3656	1.3638	0.18	2.2
30	0.7384	0.7406	0.0022	1.3543	1.3523	0.20	2.0
50	0.7520	0.7537	0.0017	1.3298	1.3295	0.03	1.9
100	0.7859	0.7859	0	1.2724	1.2724	0	0

[1] refers to cc. of alcohol per 100cc. blend before mixing
[2] Sp. G. = 0.7212 + 0.000647 $\times$ per cent alcohol
[3] Sp. V. = 1.3866 + 0.001142 $\times$ per cent alcohol

will be noted that neither the viscosities nor fluidities are additive. It will be noted that the addition of alcohol up to 6 per cent yields systems of lower viscosity than either liquid alone. Up to, and including 50 per cent alcohol, the highest concentration in the series, the observed viscosities are less than those calculated on a linear basis. Up to and including 5 per cent alcohol the fluidity is greater than that of either liquid alone. Up to 20 per cent alcohol the fluidities are greater than those calculated on the additive basis while above 20 per cent, and up to 50 per cent, the highest concentration of alcohol used, the fluidities are less than those calculated on the additive basis.

Bingham (3) outlines four classes of fluidity curves: I. The simplest case in which the fluidity is additive. There is no volume change on mixing, and it is assumed that the components neither dissociate nor interact with each other on mixing. II. There is a well defined expansion on mixing, accompanied by the absorption of heat. In such mixtures the fluidity

is generally greater than calculated. This increase in fluidity may be attributed to breaking down of association or to dissociation which give rise to the increase in volume. III. There is a contraction on mixing, accompanied by the evolution of heat. In such cases the fluidity is generally less than calculated. IV. When there is a combination of dissociation and association the curve may show a positive curvature over a part of its course and a negative curvature over a part, there being a point of inflection. A pair of liquids may fall into type II and yet have a tendency to unite chemically, provided the effect of dissociation predominates in all mixtures.

Evidently the fluidity curve for ethyl alcohol-gasoline mixtures falls into type IV. An examination of the data in the International Critical Table (11) shows the following systems of ethyl alcohol with another organic liquid which produce mixtures with fluidites greater than those calculated. Ethyl alcohol benzene (Dunstan (7), Getman (10), Findley (9);

TABLE 2. *Viscosities and fludities of ethyl alcohol-gasoline systems*

Ethanol % by vol. (a)	relative viscosity 25°C. (b)	Coeff. of viscosity x10³ (c)	Coeff. of vis. x10³ calc.[1] (d)	c-b (d)	Fluidity observed (e)	Fluidity calc. (f)	e-f (2)
				0			
0	0.723	4.645	4.645	0	215.3	215.3	±0
1	0.711	4.569	4.701	0.132	218.9	214.1	+4.8
2	0.710	4.555	4.758	0.223	219.1	212.9	+6.2
4	0.714	4.596	4.871	0.275	217.6	210.6	+7.0
6	0.723	4.661	4.984	0.323	214.5	208.2	+6.3
8	0.724	4.673	5.097	0.424	213.9	205.8	+8.1
10	0.745	4.816	5.209	0.493	207.6	203.5	+4.1
15	0.767	4.983	5.492	0.509	200.6	197.6	+3.0
20	0.800	5.219	5.774	0.555	191.6	191.7	−0.1
30	0.868	5.711	6.339	0.628	175.1	179.8	−4.1
50	1.040	6.968	7.467	0.459	143.5	156.2	−12.1
100	1.470	10.29	10.29	0	97.1	97.1	±0

[1] coeff. of viscosity $= 4.645 + 0.05645 \times$ per cent alcohol
[2] fluidity $= 215.3 - 1.182 \times$ per cent alcohol

ethyl alcohol-ethyl acetoacetate (Dunstan and Stubbs (8)); ethyl alcohol paraldehyde (Muchin (13); and ethyl alcohol-benzaldehyde (Dunstan (7); ethyl alcohol-anisol Baker (1).

The data on the ethyl alcohol-gasoline systems are especially analogous to the data (Dunstan (7)) on ethyl alcohol-benzene systems. The alcohol concentrations up to 20 per cent by weight (at 25°) show fluidities greater than for either solvent alone. The fluidities are greater than calculated up to 71 per cent by weight from which point the fluidity is as calculated. The effect of temperature upon such systems is striking. The data of Getman (10) and Findlay (9) show that at 15°, 20°, 25° and 30° there is a range of high concentrations of alcohol in which the fluidity is less than calculated while for 35° and 40° at concentration of alcohol greater than 70 per cent the fluidity is as calculated. At all temperatures the fluidities for alcohol concentrations less than 70 per cent are greater than calculated.

The data in table 2 show the fluidity of a 10 per cent alcohol-gasoline blend to be only 3.5 per cent less than for the gasoline and viscosity to be only 2.0 per cent greater than for gasoline. This variation is less than the

variation among various gasolines as shown by the data of Ricardo (15). This change in viscosity is so small as to be of no practical significance.

3. THE AIR-FUEL RATIOS OF ETHYL ALCOHOL-GASOLINE SYSTEMS

Ricardo (15) gives the air-fuel ratios of ethyl alcohol and of various gasolines. The air fuel ratio is the weight of air required to completely burn a pound of fuel. In table 3 are found calculated values for the air-fuel ratios of alcohol-gasoline systems. The value for gasoline is the average for eight gasolines. The theoretically correct air-fuel ratios will be a linear function of the composition by weight.

These calculations show that the 10 per cent blend requires about 4 per cent lower air-fuel ratio than does the gasoline. The data of Ricardo (15) for eight gasolines show a variation among the samples of 5 per cent. It is doubtful whether carburetor adjustments, in commercial practice are made to such close limits.

4. THE CALORIFIC VALUES OF ETHYL ALCOHOL-GASOLINE BLENDS

Ricardo (15) calculated the calorific value of ethyl alcohol and of various gasolines. The values include the latent heat of evaporation of the fuel and do not include the latent heat of the water formed by the combustion. In table 3 are given calorific values for ethyl alcohol-gasoline systems assuming these to be a linear function of composition. The data show the calorific value of the 10 per cent blend to be 3 per cent less than that of the gasoline. The variation in the calorific values of the eight gasolines amounts to 7 per cent. Because of the lower air-fuel ratio and the lower calorific value of the 10 per cent blend, it would be expected that the heat content of the air-fuel mixture would not be greatly affected and Ricardo (15) shows this to be practically the case for pure alcohol and gasoline.

5. THE LATENT HEATS OF ETHYL ALCOHOL-GASOLINE BLENDS

In table 3 are given values for the latent heats of evaporation of ethyl alcohol-gasoline systems on the assumption that they are a linear function of composition. The values for gasoline and ethyl alcohol are taken from Ricardo (15). There are also given calculated values for the fall in tem-

TABLE 3. *Air-fuel ratios, calorific values, latent heats, and fall in temperature on evaporation of ethyl alcohol-gasoline systems*

Ethanol % by vol.	Air-fuel ratios for complete combustion by wt.	Calorific values including latent heat at constant volume B T U/gal	Latent heat at constant pressure of 1 atm. B T U/gal.	Fall in temp. of correct air-fuel ratios due to latent heat F°
0	14.8	116,000	820	33.8
1	14.7	115,650	837	34.9
2	14.7	115,290	850	36.0
4	14.6	114,590	880	38.2
6	14.5	113,880	910	40.4
8	14.3	113,180	940	42.5
10	14.2	112,470	975	44.7
15	13.9	110,700	1060	50.2
20	13.6	108,940	1140	55.6
30	13.1	105,410	1300	66.3
50	11.9	98,350	1650	88.4
100	9.0	80,700	2560	143.0

perature, on evaporation, of the alcohol-gasoline systems at the proper air-fuel ratio.

Since the latent heat of alcohol is nearly three times that for gasoline, it is evident that this factor is of considerable importance in carburation. The air-fuel mixture will become colder upon evaporation for the blend than for gasoline. Ross and Ormandy (14) state that greater heat input to the intake manifold is desirable when using alcohol blends than when using gasoline. Practically, this is subject to some correction in view of the effect of alcohol upon the distillation range as shown in a previous paper of this series.

6. AIR-FUEL RATIOS IN PRACTICAL USE

From the data presented it can be predicted that the carburetor setting for a 10 per cent blend should be the same as that for gasoline and that the same air-fuel ratio will result. Information supplied by L. T. Brown of the Mechanical Engineering Department, Iowa State College (unpublished) shows this to be the result observed in dynammeter test. Numerous road tests by Moyer and Paustian (12) show that the 10 per cent blend can be used interchangeably with gasoline without any carburetor adjustments whatever.

SUMMARY

1. Systems of ethyl alcohol and gasoline expand on mixing. The maximum expansion is 0.2-0.3 per cent at 4-30 per cent alcohol. The density of the 10 per cent alcohol blend is about 0.6 per cent greater than for the basal gasoline. This difference is well within the limits of variation for various gasolines.

2. Neither the viscosities nor fluidities are additive. Systems containing up to 6 per cent alcohol have lower viscosities and higher fluidities than either the ethyl alcohol or gasoline alone. Up to 20 per cent alcohol the fluidities are greater than calculated on an additive basis while from 20 per cent up to 50 per cent alcohol, the highest concentration used, the fluidities are less than calculated on the additive basis. The viscosity of the 10 per cent blend is only 3.0 per cent greater than for gasoline. This is well within the limits of variation for various gasolines.

3. Using the values of Ricardo (13) for gasoline and alcohol the following characteristics were considered. The air-to-fuel ratio of a 10 per cent blend is about 4 per cent lower than for gasoline, while the variation among gasolines may be 5 per cent.

4. The calorific value of the 10 per cent blend is 3 per cent less than for the base gasoline while the variation among gasolines may be 7 per cent. Data are calculated for the latent heats and fall in temperature upon evaporation for the various blends. These factors show that with the blends there will be a greater heat input to the intake manifold which is equivalent to an increase in heat content.

5. All these data indicate that the carburetor setting for a 10 per cent blend should be the same as for gasoline and that the same air-to-fuel ratio would result. This is in harmony with data from dynammeter and road tests.

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A BOTANICAL SURVEY OF LEE COUNTY, IOWA

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This botanical survey of Lee County in southeastern Iowa was made because of the unique location, climate and soil of this area, and because the herbarium of Iowa State College contained few plants from this part of the state.

Lee County occupies a broadly triangular elevated plateau, bounded on its southeast and southwest sides along the Mississippi and Des Moines rivers by strips of low bottomlands that vary from five miles wide near Wever to a few hundred yards at Keokuk, where its point projects some fifteen miles further south into Missouri than any other section of Iowa. It is separated from Illinois on the east by the Mississippi River and from Missouri on the west and south by the Des Moines.

Between the upland plateau and the bottomlands is an extensive area of rolling hills more or less covered with timber. The uplands are cut by two trough-like drainage systems, both of which rise in the northwest corner of the county and proceed in a southeast direction through the timbered hills and down to the Mississippi and Des Moines rivers respectively. Between these two drainage systems is a broad flat ridge which roughly divides the county into equal parts.

According to the records of the United States Weather Bureau the annual mean temperature at Keokuk, situated at the southern tip of the county, is 52°F. which is 3° warmer than Des Moines. The average annual precipitation is 35.1 inches at Keokuk and 32.4 at Des Moines. The 25° isotherm for January runs a little north of Lee County as compared to the 20° isotherm through Des Moines.

There are three major groups of soil types in Lee County, which are distributed as follows: (1) the silt loams of the upland prairie in the northern half of the county which are adapted to corn production; (2) the poorer loam and silt loams in the hilly part of the southern half of the county that are suited chiefly to small grains and hay, and (3) the fertile but mostly poorly drained bottomland clays, loams and sands; the two former being suited to corn and the latter to truck crops.

The time available made it necessary to confine the work to a consideration of the flowering plants and ferns with particular attention to exact locations of plants and their distribution within the county, to soil relationships of the flora, to a general survey of the distribution of crop plants in their relation to the native and introduced vegetation, to the wider

distribution in Iowa of the trees and shrubs of Lee County, and to plants not heretofore reported in the state.

EARLIER PLANT COLLECTIONS IN LEE COUNTY

Although there has been no published account of the flora of Lee County, at least three other collections had been made prior to June 1931. These plants were examined and the records included in this paper. The earliest collections were those of the late Dr. Ehringer of Keokuk who made a collection of Lee County plants about thirty years ago which are now preserved in the herbarium of Carthage College at Carthage, Illinois. There were 22 species in this collection which were labeled ''from Lee County'' and a number more labeled ''from Iowa'' that undoubtedly came from Lee County. In this paper only those labeled ''from Lee County'' are recorded.

Another collection made by Mrs. Kate O'Bleanus about 30 years ago is preserved by her at her home near Keokuk. In this collection there were approximately 87 species from Lee County whose names, with a few changes, are included in this paper.

The most recent collection from Lee County is deposited in the herbarium of Iowa Wesleyan at Mt. Pleasant, Iowa, and was made by Professor H. E. Jaques and some of his students during the summer of 1929. There were 87 species in this collection, all of which have been included.

Besides these three collections, there are 14 species, mostly trees and shrubs, which were collected by the late Dr. L. H. Pammel and deposited in the Iowa State College Herbarium before June 1931.

RESULTS OF THE SURVEY
INCLUDED SPECIES

After our plants were collected, and identified, and the identification of the specimens in the previously mentioned collections were checked, they were listed in the order of Gray's Manual (7th edition). Locations and field notes were given in each case where available. In addition part of the names included in a list of plants published in the Iowa Farmer and Horticulturist at Burlington and Fairfield, Iowa, about seventy-five years ago[2] were included.

The following is a list of the capital letters used to indicate the several collections:

F = Plants collected and identified by Jess L. Fults.
I = Plants in the Iowa State College Herbarium before June 1, 1931.
O = Plants in the collection of Mrs. Kate O'Bleanus.
W = Plants collected by Prof. H. E. Jaques and students of Iowa Wesleyan at Mount Pleasant, Iowa.
C = Plants collected by Dr. Ehringer of Keokuk, Iowa, and placed in the herbarium of Carthage College, Carthage, Illinois.
B = Plant names published in the Iowa Farmer and Horticulturist, Vol. 1, Nos. 2, 3, 4, and 7, as occurring in southeastern Iowa, about 75 years ago.

SYSTEMATIC LIST AND FIELD NOTES

The nomenclature of Gray's Manual (7th edition) was followed, or of Britton and Brown's Flora of the Northern States and Canada in those

[2] Our Native Plants, Iowa Farmer and Horticulturist, Vol. I., Nos. 2, 3, 4 and 7.

cases where the plant was not described in Gray or when the name in
Britton and Brown seemed preferable.

SYSTEMATIC LIST AND FIELD NOTES
POLYPODIACEAE

Adiantum pedatum L.
FWC
Sec 8 T68N—R5W   Marion silt loam.
Asplenium acrostichoides SW.
C
Asplenium platyneuron (L.) Oakes
F
Sec 24 T68N—R4W   Lindley loam.
Athyrium Filix-femina (L). Roth.
FC
Sec 13 T66N—R6W   Memphis silt loam.
Infrequent in this locality.
Botrychium virginianum (L.) Sw.
F
Sec 26 T66N—R5W
Infrequent.
Filix fragilis (L.) Underw.
FC
Sec 13 T66N—R6W   Marion silt loam.
Onoclea sensibilis L.
W
Osmunda Claytoniana L.
FC
Sec 26 T66N—R6W   Genesee very fine sandy loam.
Polystichum acrostichoides (Michx.) Schott.
FW
Sec 13 T63N—R6W   Marion silt loam.
Infrequent in this locality.
Woodsia obtusa (Spreng.) Torr.
FWC
Sec 23 T66N—R6W   Genesee very fine sandy loam.
Fairly common.
Sec 19 T65N—R5W
Equisetum arvense L.
F
Vicinity of the Gabel Farm[3].
Equisetum Kansanum Schaffner
F
Sec 33 T67N—R6W
Infrequent.
Sec 28 T67N—R5W   Buckner loam.
Frequent on this soil.
Equisetum robustum A. Br.
F
Sec 27 T67N—R7W   Genesee silt loam.
Only two or three plants.
Sec 13 T65N—R5W   Genesee silt loam.
Sec 29 T65N—R5W   Wabash fine sandy loam.

PINACEAE

Juniperus virginiana L.
F
Sec 26 T66N—R5W   Lindley loam.
Associated with *Gleditsia triacanthos* in open park-like stands.

[3] Sec 19 T65N—R5W.

TYPHACEAE

Typha latifolia L.
FW
Sec 33 T68N—R3W Wabash clay.
Common in wet places.

NAJADACEAE

Potamogeton dimorphus Raf.
W

ALISMACEAE

Alisma Plantago-aquatica L.
FB
Sec 13 T66N—R5W Genesee very fine sandy loam.
Infrequent.
Sagittaria latifolia Willd.
F
Sec 4 T68N—R3W Wabash silty clay loam.
Common in very wet locations.

GRAMINEAE

Agropyron repens (L.) Beauv.
F
Sec 1 T65N—R5W Genesee very fine sandy loam.
Along railroad track. Naturalized from Europe.
Agropyron Smithii Rydb.
F
Sec 2 T66N—R6W Lindley loam.
Common along railroad track.
Agrostis alba L.
FW
Sec 8 T67N—R5W Marion silt loam.
Frequent in shady woods.
Sec 2 T66N—R6W Marion silt loam.
Common along roadsides.
Sec 23 T66N—R5W Genesee silt loam.
Frequent.
Sec 3 T65N—R6W Buckner fine sandy loam.
Infrequent.
Agrostis hyemalis (Walt.) B.S.P.
FC
Vicinity of Gabel Farm[4].
Agrostis perennans (Walt.) Tuckerm.
F
Sec 19 T67N—R5W Genesee very fine sandy loam.
Frequent in shady woods.
Alopecurus geniculatus L.
F
Vicinity of Gabel farm.
Andropogon furcatus Muhl.
F
Sec 34 T68N—R7W Lindley loam.
Aristida gracilis Ell.
F
Infrequent.
Aristida oligantha Michx.
F
Sec 36 T67N—R6W Putnam silt loam.

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[4] Sec. 19 T65N—R5W.

Avena sativa L.
W
Introduced from Europe.
Bouteloua curtipendula (Michx.) Torr.
F
Sec 30 T68N—R3W   Buckner silt loam.
Infrequent.
Bromus japonicus Thunb.
F
Vicinity of Gabel farm.   Introduced from Japan by way of Europe.
Bromus purgans L.
F
Sec 26 T66N—R5W   Lindley loam.
Infrequent in shady woods.
Sec 13 T66N—R6W   Marion silt loam.
In deep shady woods.
Bromus secalinus L.
F
Naturalized—from Europe.
Bromus tectorum L.
F
Sec 36 T67N—R6W   Lindley loam.
Common along railroad track.
Extensively naturalized from Europe.
Calamagrostis Macouniana Vasey.
F
Sec 27 T69N—R7W   Grundy silt loam.
Infrequent.
Cenchrus pauciflorus Benth.
   = *Cenchrus carolinianus* Walt.
F
Sec 28 T67N—R5W   Buckner fine sand.
Frequent in sand.
Dactylis glomerata L.
F
Sec 16 T65N—R5W   Marion silt loam.
Infrequent near lake shores.
Naturalized from Europe.
Danthonia spicata (L.) Beauv.
F
Diarrhena americana Beauv.
F
Sec 14 T66N—R6W   Genesee very fine sandy loam.
Rare in this locality.
Digitaria sanguinalis (L.) Scop.
F
Sec 36 T67N—R6W   Lindley loam.
Frequent.   Naturalized from Europe.
Echinochloa Crus-galli (L.) Beauv.
F
Sec 29 T67N—R7W   Union stony loam.
Frequent in wet ditches along the road.   Naturalized from Europe.
Elymus striatus Willd.
F
Sec 29 T65N—R5W   Wabash silt loam.
Frequent.
Elymus glabriflorus (Vasey) Scrib. & Ball.
F
Sec 14 T66N—R6W   Genesee very fine sandy loam.
Frequent in shady woods.   First specimen to be placed in Iowa State College Herbarium
from Iowa.

Elymus virginicus L.
F
Sec 8 T67N—R5W   Marion silt loam.
Elymus robustus Scribn. and J. G. Sm.
F
Sec 22 T67N—R5W   Buckner loam.
Frequent.
Sec 28 T68N—R5W   Genesee very fine sandy loam.
Sec 2 T66N—R6W   Lindley loam.
Common.
Elymus virginicus var. *submuticus* Hook.
FW
Sec 8 T67N—R5W   Genesee very fine sandy loam.
Eragrostis hypoides (Lam.) B.S.P.
F
Sec 24 T69N—R4W   Genesee very fine sandy loam.
Infrequent.
Eragrostis cilianensis (All.) Link.
  = *E. megastachya* (Koeler) Link.
F
Sec 24 T69N—R4W   Genesee very fine sandy loam.
Infrequent in a wet sand creek bottom.
Sec 21 T66N—R6W   Buckner silt loam.
Frequent.   Naturalized from Europe.
Eragrostis pectinacea (Michx.) Steud.
FW
Sec 34 T67N—R5W   Buckner loam.
Frequent.
Eragrostis pilosa (L.) Beauv.
F
Sec 4 T66N—R7W   Buckner very fine sandy loam.
Infrequent.   Found between ties of railroad track.
Festuca nutans Willd.
F
Sec 29 T65N—R5W   Wabash fine sandy loam.
Frequent in shady woods.
Festuca octoflora Walt.
FC
Sec 16 T65N—R5W   Marion silt loam.
Glyceria borealis (Nash) Batch.
F
Sec 20 T68N—R3W   Wabash silty clay loam.
Infrequent.   In standing water.
Glyceria nervata (Willd.) Trin.
F
Vicinity of Gabel farm.
Hordeum jubatum L.
F
Sec 19 T65N—R5W   Putnam loam.
A miserable weed introduced from Europe.
Hordeum pusillum Nutt.
F
Vicinity of Gabel Farm.
Hystrix patula Moench.
  = *H. Hystrix* Millsp.
F
Sec 8 T65N—R5W   Marion silt loam.
Infrequent.
Leersia oryzoides (L.) Sw.
F
Sec 21 T68N—R3W   Wabash silt loam.
Only location found.

Leersia virginica Willd.
F
Frequent in shady woods.

Leptoloma cognatum (Schultes) Chase
F
Sec 4 T66N—R7W Buckner very fine sandy loam.
Rather rare. Growing in a road.

Panicum agrostoides Spreng.
C

Panicum capillare L.
F
Sec 11 T68N—R5W Grundy silt loam.
Frequent in upland soils.

Panicum dichotomiflorum Michx.
F
Frequent.

Panicum huachucae Ashe.
F
Sec 23 T68N—R5W Lindley loam.
Very variable in its characters.

Panicum implicatum Scribn.
F

Panicum latifolium L.
 = *macrocarpon* Le Conte
F
Sec 29 T65N—R5W Wabash fine sandy loam.

Panicum Scribnerianum Nash.
F
Sec 34 T67N—R5W Buckner loam.
Infrequent.

Phleum pratense L.
W
Commonly cultivated. Introduced from Europe.

Poa compressa L.
F
Naturalized from Europe.

Poa pratensis L.
W
Very common.

Setaria glauca (L.) Beauv.
F
Sec 11 T68N—R5W Grundy silt loam.
Common. Naturalized from Europe.

Setaria viridis (L.) Beauv.
F
Sec 1 T65N—R5W Genesee very fine sandy loam.
Infrequent along roads.
Naturalized from Europe.

Sorghum halepense (L.) Pers.
F
Sec 29 T68N—R3W Wabash clay.

Spartina Michauxiana Hitchc.
F
Sec 22 T68N—R3W   Wabash clay.
Common along roads.
Sphenopholis pallens (Spreng.) Scribn.
C
Sorghastrum nutans (L.) Nash
F
Sec 21 T67N—R7W   Lindley loam.
Infrequent.
Sporobolus cryptandrus (Torr.) Gray
F
Sec 28 T67N—R5W   Buckner fine sand.
Triodia flava (L.) Hitchc.
   = *Tridens flavus* (L.) Hitchc.
F
T
Triplasis purpurea (Walt.) Chapm.
F
Sec 27 T67N—R5W   Buckner loam.
Infrequent. Leaves have a very acid taste.

Carex Asa-Grayi Bailey
   = *Carex Grayi* Carey
   = *Carex Grayi* Carey
F
Sec 33 T68N—R3W   Wabash clay.
Rare. Only one plant found.
Carex brachyglossa Mack.[5]
F
Sec 29 T65N—R5W   Wabash fine sandy loam.
Carex brevior (Dewey) Mack.[5]
F
Sec 36 T66N—R6W   Marion silt loam.
Infrequent on upland soils.
Carex Bicknellii Britt.
F
Sec 16 T65N—R5W   Marion silt loam.
Rare at this date—June 29, 1932.
Carex cephalophora Muhl.
FC
Sec 13 T66N—R6W   Marion silt loam.
Frequent in shady woods.
Carex cristatella Britt.
   = *cristata* Schwein.
F
Sec 23 T66N—R6W   Genesee very fine sandy loam.
Sec 4 T66N—R7W   Buckner very fine sandy loam.
Frequent.
Carex conjuncta Boott.
F
Sec 14 T66N—R6W   Genesee very fine sandy loam.
Carex crus-corvi Schuttlw.
F
Sec 33 T68N—R3W   Wabash clay.
Carex Davisii Schwein. & Torr.
F
Sec 29 T65N—R5W   Wabash fine sandy loam.
Seemed to spread by rhizomes.

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[5] Described by Mr. Kenneth K. Mackenzie since the last editions of Gray's "New Manual of Botany" and Britton and Brown's "Flora of the Northern States and Canada."

Carex festucacea Willd.
F
Sec 32 T67N—R7N Buckner very fine sandy loam.
Note the hollow stems which are rare in this genus.
Carex gravida Bailey.
F
Carex hirsutula Mack.
F
Sec 36 T66N—R6W Marion silt loam.
Note the hairy leaves.
Carex hystricina Muhl.
C
Carex Jamesii Schwein.
F
Carex lanuginosa Michx.
F
Sec 36 T67N—R6W Lindley loam.
Carex laxiflora Lam.
C
Carex lupuliformis Sartwel.
F
Sec 20 T68N—R3W Wabash silty clay loam.
Carex lupulina Muhl.
F
Sec 19 T65N—R5W Wabash clay.
Sec 28 T67N—R6W Lindley loam.
Sec 33 T68N—R3W Wabash clay.
Infrequent.
Carex muskingumensis Schwein.
F
Sec 33 T68N—R3W Wabash clay.
Frequent.
Carex pennsylvanica Lam.
F
Carex plana Michx. (*C. Muhlenbergii* var. *enervis* Boott.)
F
Sec 28 T67N—R5W Buckner fine sand.
Carex retrorsa Schwein.
F
Sec 29 T67N—R7W Marion silt loam.
Common in wet ravines.
Carex rosea Schkuhr.
F
Sec 23 T66N—R6W Genesee very fine sandy loam.
Carex scoparia Schkuhr.
F
Sec 29 T65N—R5W Wabash fine sandy loam.
Infrequent.
Carex Shriveri Britt.
   = *C. granularis* var. *Haleana* (Olney) Porter
F
Sec 13 T66N—R6W Marion silt loam.
Infrequent.
Carex straminea var. *echinodes* Fernald
F
Sec 19 T65N—R5W Putnam silt loam.
Carex tenella Schkuhr.
F
Carex tribuloides Wahlenb.
F
Sec 23 T66N—R6W Genesee very fine sandy loam.
Frequent.
Sec 19 T65N—R5W Wabash clay.
Infrequent on this soil.

Carex typhina Michx.
F
Sec 33 T68N—R3W   Wabash clay.
Carex umbellata Schkuhr.
F
Sec 23 T66N—R6W   Genesee very fine sandy loam.
Infrequent in damp woods.
Carex vulpinoidea Michx.
F
Sec 28 T68N—R4W   Lindley loam.
Carex xanthocarpa Bicknell.
   = *C. setacea* var. *ambigua* (Barratt) Fernald
F
Sec 13 T66N—R6W   Marion silt loam.
Frequent in shady woods.
Cyperus acuminatus Torr. & Hook.
F
Sec 5 T67N—R5W   Marion silt loam.
Rare. An annual.
Cyperus esculentus L.
F
Sec 27 T67N—R7W   Union stony loam.
Cyperus filiculmis Vahl.
F
Sec 3 T65N—R6W   Buckner fine sandy loam.
Rare. In the school house yard ¼ mile west of Connables, Iowa.
Cyperus Schweinitzii Torr.
F
Sec 27 T67N—R5W   Buckner loam.
Frequent on sandy bottom soils.
Heavily infected with *Puccinia cyperii* Arth.
Sec 34 T67N—R5W   Buckner loam.
Frequent.
Sec 36 T67N—R6W   Lindley loam.
Infrequent in this soil.
Cyperus speciosus Vahl.
   = *C. ferax* Rich. of Gray's Manual
C
Eleocharis acicularis (L.) R. & S.
F
Sec 4 T68N—R3W   Wabash silty clay loam.
Common in wet mud.
Eleocharis obtusa (Willd.) Schultes
F
Sec 19 T65N—R5W   Wabash clay.
Infrequent.
Sec 36 T67N—R6W   Lindley loam.
Common on railroad track ballast.
Eleocharis palustris (L.) R. & S.
F
Sec 19 T65N—R5W   Wabash clay.
Common in wet places.
Scirpus americanus Pers.
F
Sec 2 T66N—R6W   Marion silt loam.
Rare along railroad track.
Scirpus atrovirens Muhl.
F
Sec 16 T65N—R5W   Marion silt loam.
Common in wet ground.
Scirpus cyperinus (L.) Kunth.
F
Sec 20 T68N—R3W   Wabash silty clay loam.
Infrequent.

Scirpus lineatus Michx.
F

Scirpus validus Vahl.
FC
Sec 33 T68N—R3W   Wabash clay.
Infrequent.

ARACEAE

Arisaema Dracontium (L.) Schott.
W

Arisaema triphyllum (L.) Schott.
FOB

COMMELINACEAE

Commelina virginica L.
F
Sec 28 T67N—R5W   Buckner loam.
Tradescantia reflexa Raf.
F
Tradescantia virginiana L.
OCB

JUNCACEAE

Juncus acuminatus Michx.
F
Sec 19 T65N—R5W   Wabash clay.
Infrequent.
Juncus balticus var. *littoralis* Engelm.
F
Sec 36 T67N—R6W   Lindley loam.
Infrequent.
Juncus bufonius L.
F
Sec 33 T68N—R4W   Lindley loam.
Juncus effusus L.
F
Juncus secundus Beauv.
   var.?
F
Sec 29 T65N—R5W   Wabash fine sandy loam.
Infrequent.
Juncus tenuis Willd.
F
Sec 33 T67N—R6W   Putnam loam.
Frequent to common in shady places along paths.
Sec 19 T65N—R5W   Putnam loam.
Common in shady places.
Juncus Torreyi Coville.
F
Sec 36 T67N—R6W   Lindley loam.
Frequent along railroad tracks.

LILIACEAE

Allium canadense L.
F
Allium mutabile Michx.
F
Sec 36 T67N—R6W   Lindley loam.
Infrequent.

Asparagus officinalis L.
FW
Sec 13 T65N—R5W Grundy silt loam.
A common escape. Introduced from Europe.

Erythronium albidum Nutt.
O

Hemerocallis fulva L.
F
Sec 31 T66N—R5W Genesee very fine sandy loam. Frequent as an escape.

Lilium Michiganense Farw.
F
Sec 36 T67N—R6W Lindley loam.
Rare. ¼ mile S.W. of Junction of the A. T. and S. F. railroad with the hard road from Donnellson to Keokuk, Iowa.

Polygonatum commutatum (R. & S.) Dietr.
F
Sec 13 T66N—R5W Genesee very fine sandy loam.

Polygonatum commutatum (R. & S.) Dietr.
O

Smilacina racemosa (L.) Desf.
FO
Sec 14 T66N—R6W Genesee very fine sandy loam.
Frequent under dense shade.

Smilax ecirrhata (Engelm.) Wats.
F

Smilax rotundifolia L.
F
Sec 11 T65N—R5W Lindley loam.
Infrequent.

Trillium recurvatum Beck.
OBF

Uvularia grandiflora Sm.
FB

Uvularia perfoliata L.
W

AMARYLLIDACEAE

Hypoxis hirsuta (L.) Coville.
O

IRIDACEAE

Belamcanda chinensis (L.) DC.
F
Sec 25 T68N—R4W Marion silt loam.
Infrequent as an escape. Introduced from Europe.

Iris versicolor L.
FWB
Sec 19 T65N—R5W Wabash clay.
Infrequent.

Sisyrinchium campestre Bicknell
FO
Sec 28 T64N—R4W Memphis silt loam.
Rare.

ORCHIDACEAE

Cypripedium parviflorum Salisb.
  var. *pubescens* (Willd.) Knight
O

SALICACEAE

Populus alba L.
F
Sec 27 T67N—R7W Marion silt loam.
Introduced from Europe.

Populus deltoides Marsh.
F
Sec 17 T65N—R5W Lindley loam.
In a dry creek bottom. Frequent.
Populus tremuloides Michx.
F
Sec 28/33 T67N—R6W Putnam loam.
Salix amygdaloides Anders.
I

Salix discolor Muhl.
I

Salix nigra Marsh.
F
Sec 27 T67N—R7W Genesee silt loam.
Sec 28 T66N—R5W Memphis silt loam.
Sec 26 T66N—R5W Genesee silt loam.
Salix interior Rowlee.
  = *S. longifolia* Muhl.
F
Sec 4 T68N—R3W Wabash silty clay loam.
Common.
Sec 4 T67N—R5W Memphis silt loam.
Frequent.

JUGLANDACEAE

Carya alba (L.) K. Koch.
F
Infrequent.
Carya cordiformis (Wang.) K. Koch.
F
Sec 30 T69N—R3W Lindley loam.
Frequent.
Carya ovata (Mill.) K. Koch.
F
Sec 27 T67N—R7W Marion silt loam.
Common.
Juglans cinerea L.
F
Juglans nigra L.
I

BETULACEAE

Betula nigra L.
F
Sec 12 T65N—R6W
Frequent along Sugar Creek.
Carpinus caroliniana Walt.
FB
Corylus americana Walt.
FW
Sec 17 T65N—R5W Lindley loam.
Ostrya virginiana (Mill.) Willd.
FWB
Common in shady woods.

FAGACEAE

Quercus alba L.
FW
Sec 30 T69N—R3W   Lindley loam.
Common.

Quercus bicolor Willd.
F
Sec 20 T65N—R5W   Putnam loam.
Sec 28 T67N—R6W   Genesee silt loam.
Sec 14 T66N—R6W   Genesee very fine sandy loam.

X *Quercus Bushii* Sargent
   (*Quercus velutina* x *marilandica*)
F
Sec 33 T67N—R7W

Quercus imbricaria Michx.
W

Quercus macrocarpa Michx.
F
Sec 2 T66N—R6W   Genesee very fine sandy loam.
Sec 34 T68N—R7W   Lindley loam.
Common on this soil.

Quercus marilandica Muench.
F
Sec 8 T65N—R5W   Marion silt loam.
Quite common in one location near Summit School.

Quercus maxima Ashe.
FI
Sec 8 T67N—R5W   Marion silt loam.

Quercus Muhlenbergii Engelm.
F

Quercus palustris Muench.
F
Frequent.

Quercus stellata Wang.
FW
Sec 36 T66N—R6W
Sec 25 T66N—R6W   Marion silt loam.

Quercus velutina Lam.
FW

URTICACEAE

Cannabis sativa L.
F
Sec 34 T67N—R5W   Buckner loam.
Frequent.   An introduction from Europe.

Celtis occidentalis L.
FW
Sec 32 T66N—R6W   Buckner loam.

Celtis occidentalis
   var. *crassifolia* (Lam.) Gray
I

Humulus Lupulus L.
F

Laportea canadensis (L.) Gaud.
   = *Urticastrum divaricatum* (L.) Kuntze
F
Sec 32 T66N—R6W   Wabash silt loam.
Frequent in shady woods along streams.

Maclura pomifera (Raf.) Schneider.
F
Sec 2 T66N—R5W   Lindley loam.
An escape in the southern part of Iowa.   Native from Missouri to Texas.

Morus alba L.
F
Frequent as an escape. Naturalized from Europe.
Morus rubra L.
I

Parietaria pennsylvanica Muhl.
C

Ulmus americana L.
FW
Sec 34 T66N—R6W Buckner silt loam.
Common.
Ulmus fulva Michx.
W

Ulmus racemosa Thomas.
I

Urtica gracilis Ait.
F

SANTALACEAE

Comandra umbellata (L.) Nutt.
O

ARISTOLOCHIACEAE

Asarum canadense L.
FOB

POLYGONACEAE

Dioscorea villosa L.
FW
Sec 19 T65N—R5W
In second growth hickory woods.
Sec 2 T66N—R6W Genesee very fine sandy loam.
Common.
Polygonum acre HBK.
F
Frequent.
Polygonum aviculare L.
F

Polygonum Convolvulus L.
F
Sec 1 T65N—R5W Genesee very fine sandy loam.
Infrequent. Naturalized from Europe.
Polygonum Hydropiper L.
C

Polygonum lapathifolium L.
F

Polygonum Muhlenbergii (Meisn.) Wats.
C

Polygonum pennsylvanicum L.
F
Sec 21 T66N—R6W Marion silt loam.
Common along roads in loose soil.
Sec 22 T68N—R3W
Sec 1 T65N—R5W Genesee very fine sandy loam.
Infrequent along railroad tracks.
Polygonum Persicaria L.
W
Naturalized from Europe.
Polygonum ramosissimum Michx.
F
Sec 28 T67N—R5W Buckner loam.
Infrequent.

Polygonum sagittatum L.
Sec 19 T67N—R5W Genesee very fine sandy loam.
Infrequent.

Polygonum scandens L.
F

Polygonum tenue Michx.
F
Sec 28 T64N—R4W Memphis silt loam.
Infrequent on dry hill knolls.

Polygonum virginianum L.
F
Sec 30 T68N—R3W Buckner silt loam.
Frequent.

Rumex Acetosella L.
FW
Introduced from Europe.

Rumex altissimus Wood.
F

Rumex Britannica L.
C

Rumex crispus L.
F
Naturalized from Europe.

Rumex verticillatus L.
F
Sec 28 T67N—R6W Lindley loam.
Infrequent. Growing in water with some sedges.

CHENOPODIACEAE

Chenopodium album L.
FB
Sec 29 T65N—R5W Wabash fine sandy loam.
Common. Naturalized from Europe.

Chenopodium ambrosioides L.
FB
Sec 10 T66N—R6W Putnam loam.
Infected with *Cercospora dubia* (Riess.) Wint.

Chenopodium urbicum L.
C

Cycloloma atriplicifolium (Spreng.) Coulter.
F
Sec 36 T67N—R6W Lindley loam.
Common on railroad ballast.
Sec 28 T65N—R5W Buckner fine sand.
Sec 27 T67N—R5W Buckner loam.

AMARANTHACEAE

Acnida tuberculata Moq.
F
Sec 33 T68N—R3W Wabash clay.
Frequent.

Amaranthus blitoides Wats.
F
Sec 14 T67N—R5W Buckner very fine sandy loam.
Frequent. Naturalized from west of the Rocky Mountains.

Froelichia campestris Small.
    = *F. floridana* (Nutt.) Moq.
F
Sec 28 T67N—R5W Buckner fine sand.
Infrequent. Along fences.
Sec 32 T67N—R5W Buckner fine sandy loam.

PHYTOLACCACEAE

Phytolacca decandra L.
F
Sec 13 T65N—R6W
Infrequent.
Sec 36 T68N—R3W Wabash clay.
Rare at this date, July 29, 1931.

NYCTAGINACEAE

Allionia nyctaginea Michx.
    = *Oxybaphus nyctaginea* (Michx.) Sweet.
F

CARYOPHYLLACEAE

Cerastium nutans Raf.
CF
Cerastium viscosum L.
C
Cerastium vulgatum L.
F
Sec 17 T65N—R5W Lindley loam.
Common but only a few flowers at this date. Naturalized from Europe.
Dianthus barbatus L.
W
Saponaria officinalis L.
F
Sec 1 T65N—R5W Genesee very fine sandy loam.
Common along railroad track.
Sec 28 T67N—R5W Buckner loam.
Frequent to common. Naturalized from Europe.
Silene alba Muhl.
    = *S. nivea* (Nutt.) Otth.
F
Sec 4 T66N—R7W Buckner very fine sandy loam.
Silene antirrhina L.
C
Silene media (L.) Cyrill.
C
Silene stellata (L.) Ait.
FB
Sec 4 T66N—R7W Buckner very fine sandy loam.
Infrequent.

AIZOACEAE

Mollugo verticillata L.
F
Sec 29 T67N—R7W Marion silt loam.
Naturalized from further south.

PORTULACACEAE

Claytonia virginica L.
OFB
Portulaca oleracea L.
F
Sec 10 T66N—R6W Putnam loam.
Infrequent. In plowed corn fields.
Naturalized from Europe.

NYMPHAEACEAE

Castalia tuberosa (Paine) Greene.
C

RANUNCULACEAE

Anemone canadensis L.
F

Sec 33 T68N—R3W Wabash clay.
Common in wet bottomland soils.
Anemone quinquefolia L.
O
Anemone virginiana L.
FB
Sec 13 T66N—R6W Marion silt loam.
Infrequent in damp shady woods.
Sec 2 T65N—R5W Lindley loam.
Sec 13 T65N—R6W
Anemonella thalictroides (L.) Spach.
F

Aquilegia canadensis L.
OWB
Clematis Pitcheri T. & G.
F
Sec 2 T66N—R6W Genesee very fine sandy loam.
Infrequent.
Sec 2 T66N—R5W Genesee very fine sandy loam.
Delphinium azureum Michx.
WB
Delphinium tricorne Michx.
C
Hepatica acutiloba DC.
O
Ranunculus acris L.
O
Ranunculus abortivus L.
FO
In shady woods.
Ranunculus fascicularis Muhl.
FOB
Ranunculus septentrionalis Poir.
F
Thalictrum dasycarpum Fisch. & Lall.
F
Sec 23 T68N—R5W Grundy silt loam.
Frequent.

MENISPERMACEAE

Menispermum canadense L.
FB
Sec 2 T66N—R6W Marion silt loam.

ANONACEAE

Asimina triloba Dunal.
FW
Sec 1 T65N—R5W Memphis silt loam.
Frequent on north slopes to Mississippi River.
Podophyllum peltatum L.
FO

BERBERIDACEAE

Berberis vulgaris L.
I
Naturalized from Europe.
Caulophyllum thalictroides (L.) Michx.
C

PAPAVERACEAE

Sanguinaria canadensis L.
OB

FUMARIACEAE

Corydalis aurea Willd.
OF
Dicentra canadensis (Goldie) Walp.
FB

CRUCIFERAE

Arabis canadensis L.
F

Barbarea vulgaris R.Br.
C

Brassica juncea (L.) Cosson
F
Naturalized from Europe.
Brassica nigra (L.) Koch.
FW
Sec 1 T65N—R5W Genesee very fine sandy loam.
Common along railroad near Sandusky, Iowa.
Naturalized from Europe.
Capsella Bursa-pastoris (L.) Medic.
WO
Naturalized from Europe.
Cardamine hirsuta L.
C

Cardamine parviflora L.
F

Draba caroliniana Walt.
F

Erysimum cheiranthoides L.
FB
Sec 24 T69N—R4W Genesee very fine sandy loam.
Frequent.
Lepidium densiflorum Schrad.
  = *L. apetalum* in Gray's Manual.
F

Lepidium virginicum L.
FW
Sec 27 T67N—R7W Genesee silt loam.
Radicula palustris (L.) Muench.
F
Sec 31 T67N—R5W Putnam loam.
Infrequent.
Raphanus sativus L.
W

Sisymbrium altissimum L.
F

Sisymbrium canescens Nutt.
F

Sisymbrium officinale (L.) Scop.
FO
Sec 24 T69N—R4W Genesee very fine sandy loam.
Naturalized from Europe.

CAPPARIDACEAE

Polanisia trachysperma T. & G.
F
Sec 32 T66N—R6W Buckner very fine sandy loam.
Frequent in this soil.
Sec 33 T68N—R3W
Common in sand along levees, etc.

SAXIFRAGACEAE

Heuchera hispida Pursh.
F
Sec 9 T65N—R5W Lindley loam.
Rare.
Penthorum sedoides L.
F
Sec 4 T68N—R3W Wabash silty clay loam.
Infrequent in wet soil.
Ribes missouriense Nutt.
  = *gracile* Michx.
F
Sec 1 T65N—R5W Memphis silt loam.

PLATANACEAE

Platanus occidentalis L.
I

ROSACEAE

Agrimonia gryposepala Wallr.
F
Sec 15/22 T66N—R6W Grundy silt loam.
Infrequent.
Agrimonia parviflora Ait.
F
Aruncus sylvester Kosteletzsky
  = *A. Aruncus* (L.) Karst.
FB
Sec 9 T65N—R5W Lindley loam.
Infrequent.
Sec 23 T66N—R6W Genesee very fine sandy loam.
Infrequent.
Crataegus Crus-galli L.
F
Sec 19 T65N—R5W
Crataegus Margaretta Ashe.
F
Sec 8 T67N—R5W Marion silt loam.
Crataegus mollis (T. & G.) Scheele.
IF
Fragaria virginiana Duchesne
F
Sec 20 T65N—R5W Wabash fine sandy loam.
Geum canadense Jacq.
  = *album* J. F. Gmel.
F
Sec 14 T66N—R6W Genesee very fine sandy loam.
Geum virginianum L.
F
Sec 4 T68N—R3W Wabash silty clay loam.
Frequent.
Sec 3 T65N—R6W Wabash silt loam.
Infrequent.
Malus ioensis (Wood) Britt.
  = *Pyrus ioensis* (Wood) Bailey
F
Sec 23 T68N—R5W Lindley loam.
Frequent.
Sec 30 T65N—R5W
Abundant.
Potentilla arguta Pursh.
F
Sec 36 T67N—R6W Lindley loam.
Infrequent.

Potentilla canadensis L.
FO
Sec 29 T67N—R7W   Marion silt loam.
Potentilla monspeliensis L.
FW
Sec 23 T66N—R6W   Genesee very fine sandy loam.
Prunus americana Marsh.
F
Sec 36 T66N—R6W   Buckner silt loam.
Prunus Persica (L.) Stokes.
I
Prunus serotina Ehrh.
F
Sec 2 T65N—R5W   Lindley loam.
Infrequent.
Prunus virginiana L.
F
Sec 13 T66N—R5W   Genesee very fine sandy loam.
Rosa setigera Michx.
C
Rosa virginiana Mill.
F
Sec 13 T66N—R6W   Marion silt loam.
Frequent.
Sec 14 T67N—R5W   Buckner fine sand.
Frequent.
Rosa Woodsii Lindl.
I
Rubus Baileyanus Britt.
  = *R. villosus* var. *humifusus* T. & G.
I
Rubus villosus Ait.
FW
Sec 36 T66N—R6W   Buckner silt loam.
Along railroad tracks.
Spiraea alba DuRoi.
F
Sec 19 T65N—R5W   Wabash clay.
Infrequent.

LEGUMINOSAE

Amorpha canescens Pursh.
F
Sec 17 T65N—R5W   Marion silt loam.
Frequent.
Sec 28 T67N—R6W
Found on a steep eroded slope.
Amorpha fruticosa L.
IB
Amphicarpa Pitcheri T. & G.
F
Sec 36 T66N—R6W   Buckner fine silt loam.
Apios tuberosa Muench.
F
Sec 9 T65N—R5W   Lindley loam.
Infrequent in shady woods.
Astragalus canadensis L.
F
Sec 14 T66N—R6W   Marion silt loam.
Astragalus distortus T. & G.
F

Baptisia bracteata (Muhl.) Ell.
F
Sec 33 T68N—R4W   Lindley loam.
Baptisia leucantha T. & G.
F
Sec 15/22 14/23 T66N—R6W   Putnam silt loam.
Frequent.
Sec 17 T65N—R5W   Marion silt loam.
Infrequent.
Cassia Chamaecrista L.
FWB
Sec 32 T67N—R7W   Memphis silt loam.
Common along roadbanks.
Cercis canadensis L.
FW
Crotalaria sagittalis L.
F
Sec 15 T66N—R6W   Putnam loam.
Infrequent.
Desmodium bracteosum var. *longifolium* (T. & G.) Robinson
F
Sec 25 T66N—R4W   Marion silt loam.
Infrequent.
Desmodium canadense (L.) DC.
FB
Sec 11 T65N—R5W   Grundy silt loam.
Infrequent along railroad tracks.
Desmodium Dillenii Darl.
C
Desmodium grandiflorum (Walt.) DC.
F
Sec 13 T66N—R6W   Marion silt loam.
Infrequent.
Sec 9 T65N—R5W   Lindley loam.
Desmodium illinoense Gray
F
Sec 14 T67N—R5W   Buckner very fine sandy loam.
Frequent.
Desmodium nudiflorum (L.) DC.
F
Sec 23 T68N—R5W   Lindley loam.
Desmodium paniculatum (L.) DC.
C
Gleditsia triacanthos L.
FW
Sec 26 T66N—R5W   Memphis loam.
Lespedeza capitata Michx.
F
Sec 24 T66N—R6W   Marion silt loam.
Infrequent.
Lespedeza violacea (L.) Pers.
F
Sec 13 T66N—R6W   Marion silt loam.
Infrequent.
Lespedeza virginica (L.) Britt.
F
Sec 20 T67N—R7W   Union stony loam.
Infrequent.
Medicago lupulina L.
F
Sec 36 T67N—R6W   Lindley loam.
Frequent along railroad.

Medicago sativa L.
FW
Sec 14 T65N—R5W   Genesee silt loam.
Along roadsides.
Melilotus alba Desr.
FWO
Sec 1 T66N—R6W   Lindley loam.
Naturalized from Europe.
Petalostemum purpureum (Vent.) Rydb.
F
Psoralea Onobrychis Nutt.
F
Sec 36 T68N—R4W   Marion silt loam.
Infrequent.
Sec 1 T65N—R5W   Genesee very fine sandy loam.
Robinia Pseudo-Acacia L.
F
Native further south.
Strophostyles helvola (L.) Britt.
F
Sec 32 T67N—R7W   Memphis silt loam.
Frequent.
Sec 28 T67N—R6W   Genesee silt loam.
Frequent. Found on a steep eroded slope.
Tephrosia virginiana (L.) Pers.
FB
Sec 28 T67N—R5W   Buckner fine sand.
Trifolium hybridum L.
F
Introduced from Europe.
Trifolium pratense L.
FWO
Sec 1 T66N—R6W   Lindley loam.
Infrequent along roadsides.
Introduced from Europe.
Trifolium repens L.
FO
Sec 2 T66N—R6W   Lindley loam.
Infrequent along roads. Doubtfully indigenous to America.

OXALIDACEAE

Oxalis cymosa Small
  = *corniculata* L. (Gray's Manual)
F
Sec 26 T66N—R5W   Genesee silt loam.
Infrequent. Nearly prostrate.
Sec 14 T66N—R6W   Genesee very fine sandy loam.
Oxalis stricta L.
FOW
Oxalis violacea L.
OB

GERANIACEAE

Geranium carolinianum L.
F
Geranium maculatum L.
FO

RUTACEAE

Ptelea trifoliata L.
WB

Zanthoxylum americanum Mill.
FW
Sec 30 T69N—R3W Lindley loam.
Infrequent. Leaves have a lemon odor.
Sec 1 T65N—R5W Memphis silt loam.
Infrequent on north slopes to Mississippi River.

SIMARUBACEAE

Ailanthus glandulosa Desf.
I
Introduced from Asia.

POLYGALACEAE

Polygala sanguinea L.
CF
Sec 8 T65N—R5W Marion silt loam.
Infrequent.
Sec 23 T66N—R6W Genesee very fine sandy loam.
Sec 33 T68N—R4W Memphis silt loam.
Frequent.
Polygala verticillata L.
F
Sec 23 T66N—R6W Genesee very fine sandy loam.
Infrequent.

EUPHORBIACEAE

Acalypha virginica L.
F
Sec 36 T67N—R6W Lindley loam.
Common on railroad track ballast.
Croton capitatus Michx.
C
Croton glandulosus L.
  var. *septentrionalis* Muell. Arg.
F
Sec 33 T67N—R5W Buckner fine sand.
Infrequent.
Sec 28 T66N—R5W Buckner fine sand.
Frequent.
Sec 10 T66N—R6W Putnam silt loam.
Frequent. Said to make horses slobber.
Croton monanthogynus Michx.
C
Euphorbia corollata L.
FB
Sec 11 T68N—R5W
Common.
Sec 32 T67N—R7W
Frequent along railroads.
Euphorbia Cyparissias L.
C
Euphorbia maculata L.
FCB
Sec 29 T67N—R7W Lindley loam.
Infrequent.
Euphorbia Peplus L.
C

ANACARDIACEAE

Rhus canadensis Marsh.
F
Quite common.

Rhus glabra L.
F
Sec 10 T68N—R4W   Lindley loam.
Common.
Sec 29 T65N—R5W   Wabash fine sandy loam.
Sec 33 T67N—R6W   Putnam loam.
Frequent along roads.
Celastrus scandens L.
F
Sec 2 T66N—R6W   Genesee very fine sandy loam.
Infrequent.
Evonymus atropurpureus Jacq.
WB

ACERACEAE

Acer Negundo L.
F
Sec 32 T66N—R6W   Wabash silt loam.
Frequent.
Acer nigrum Michx.
  = *A. saccharum* var. *nigrum* (Michx.) Britt.
F
Sec 33 T67N—R7W   Memphis silt loam.
Common.
Acer saccharinum L.
FW
Sec 2 T66N—R6W   Marion silt loam.
Frequent on upland soils.
Acer saccharum Marsh.
W

STAPHYLEACEAE

Staphylea trifolia L.
WF

SAPINDACEAE

Aesculus glabra Willd.
F
Aesculus glabra Willd.
  var. *arguta* (Buckley) Robinson
FW
Sec 1 T65N—R5W   Memphis silt loam.
Infrequent in hickory maple woods.

BALSAMINACEAE

Impatiens biflora Walt.
F
Sec 13 T66N—R5W   Genesee very fine sandy loam.
Impatiens pallida Nutt.
FWB
Sec 23 T66N—R6W   Genesee very fine sandy loam.
Common.

RHAMNACEAE

Ceanothus americanus L.
FWB
Sec 2 T66N—R6W   Genesee very fine sandy loam.
Infrequent.
Sec 28 T67N—R6W   Genesee silt loam.
Frequent.
Rhamnus lanceolata Pursh.
F
Sec 26 T67N—R7W   Memphis loam.
Infrequent.

VITACEAE

Psedera quinquefolia (L.) Greene.
C
Vitis cordifolia Michx.
F
Rare
Vitis labrusca L.
W
Cultivated.
Vitis vulpina L.
F

TILIACEAE

Tilia americana L.
F
Sec 32 T67N—R7W Lindley loam.
Infrequent to frequent.
Tilia europaea L.
C
Cultivated.

MALVACEAE

Abutilon Theophrasti Medic.
F
Sec 20 T68N—R4W Grundy silt loam.
A common cornfield and barnyard weed.
Althaea rosea Cav.
F
Sec 13 T65N—R5W Genesee silt loam.
An escape from cultivation.
Introduced from China.
Hibiscus militaris Cav.
FB
Sec 36 T63N—R3W Wabash clay.
Infrequent.
Malva rotundifolia L.
O
Naturalized from Europe.
Sida spinosa L.
F
Sec 10 T66N—R6W Marion silt loam.
Sec 33 T68N—R3W Wabash clay.
Infrequent. Naturalized from the tropics.

HYPERICACEAE

Hypericum Ascyron L.
F
Sec 27 T67N—R7W Lindley loam.
Very infrequent. A shrub with large yellow flowers.
Hypericum cistifolium Lam.
F
Sec 2 T66N—R6W Genesee very fine sandy loam.
Infrequent.
Hypericum ellipticum Hook.
C
Hypericum perforatum L.
FB
Sec 15 T66N—R6W Putnam loam.
Frequent.
Sec 29 T65N—R5W Wabash sandy loam.
Hypericum prolificum L.
FB
Sec 26 T67N—R7W Memphis silt loam.
Infrequent.

Hypericum punctatum Lam.
F
Sec 4 T66N—R7W Buckner very fine sandy loam.
Frequent along railroad tracks.

CISTACEAE

Lechea tenuifolia Michx.
F
Sec 2 T66N—R6W Genesee very fine sandy loam.
Sec 28 T64N—R4W Lindley loam.
Frequent.

VIOLACEAE

Viola palmata L.
O
Viola papilionacea Pursh.
F
Viola pedata L.
OB
Viola scabriuscula Schwein.
  = *eriocarpa* Schwein.
FOB
Viola striata Ait.

THYMELAEACEAE

Dirca palustris L.

LYTHRACEAE

Cuphea petiolata (L.) Koehne.
C
Lythrum alatum Pursh.
FB
Sec 1 T65N—R5W Genesee very fine sandy loam.
Infrequent in wet ditches.
Sec 2 T66N—R6W Genesee very fine sandy loam.

ONAGRACEAE

Circaea lutetiana L.
FB
Sec 33 T67N—R6W Putnam loam.
Common in shady woods.
Ludwigia polycarpa Short & Peter.
FB
Sec 29 T67N—R7W Lindley loam.
Infrequent along roads.
Oenothera laciniata Hill.
F
Sec 29 T67N—R7W Lindley loam.
Infrequent. Introduced from the western plains.
Oenothera muricata L.
F
Sec 28 T68N—R4W Genesee very fine sandy loam.
Infrequent. Found in a timothy field.
Oenothera rhombipetala Nutt.
F
Sec 32 T66N—R6W Buckner fine sand.

UMBELLIFERAE

Anethum graveolens L.
W
Chaerophyllum procumbens (L.) Crantz.
F

Cicuta maculata L.
FB
Sec 32 T67N—R6W   Marion silt loam.
Infrequent.
Sec 2 T65N—R5W   Lindley loam.
Along a roadside.
Cryptotaenia canadensis (L.) DC.
FC
Sec 29 T65N—R5W   Wabash fine sandy loam.
Infrequent in shady woods.
Daucus Carota L.
F
Sec 36 T68N—R6W   Putnam loam.
Infrequent on upland soils.
Sec 2 T65N—R5W   Lindley loam.
Naturalized from Europe.
Eryngium yuccifolium Michx.
F
Sec 36 T67N—R6W   Lindley loam.
Infrequent.
Osmorrhiza longistylis (Torr.) DC.
FO
Sec 29 T65N—R5W   Wabash fine sandy loam.
Frequent in shady woods.
Osmorhiza Claytoni (Michx.) Clarke.
W
Pastinaca sativa L.
FW
Sec 1 T65N—R5W   Genesee very fine sandy loam.
Common along railroad banks.
Sec. 28 T68N—R4W   Grundy silt loam.
Naturalized from Europe.
Sanicula canadensis L.
FW
Sec 13 T65N—R6W
In shady woods.
Taenidia integerrima (L.) Drude.
F
Thaspium barbinode (Michx.) Nutt.
F
Sec 23 T68N—R5W   Lindley loam.
Zizia aurea (L.) Koch.
F
Sec 9 T65N—R5W   Lindley loam.
Infrequent.
Sec 32 T67N—R6W   Marion silt loam.

CORNACEAE

Cornus alternifolia L.f.
I
Cornus Amomum Mill.
IC
Cornus asperifolia Michx.
FW
Sec 14 T65N—R5W
In shady woods.
Sec 25 T66N—R4W   Marion silt loam.
Frequent.
Cornus circinata L'Hér.
I

Cornus paniculata L'Hér.
FB
Sec 28/33 T67N—R6W   Putnam loam.
Fairly common.

PRIMULACEAE

Anagallis arvensis L.
C

Androsace occidentalis Pursh.
F

Steironema ciliatum (L.) Raf.
F
Sec 9 T65N—R5W   Lindley loam.
Infrequent in shady woods.
Sec 29 T67N—R7W   Union stony loam.
Infrequent.
Sec 23 T66N—R6W   Genesee very fine sandy loam.
Infrequent.

Steironema lanceolatum (Walt.) Gray.
F
Sec 4 T68N—R3W   Wabash silty clay loam.
Frequent.

OLEACEAE

Fraxinus americana L.
  = *F. pennsylvanica* var. *lanceolata* (Borkh.) Sarg.
F
Sec 36 T66N—R6W   Buckner silt loam.

Fraxinus lanceolata Bork.
F
Sec 14 T66N—R6W   Genesee very fine sandy loam.
Infrequent.

Fraxinus nigra Marsh.
I

Fraxinus pennsylvanica Marsh.
F
Sec 32 T67N—R5W   Buckner fine sandy loam.
A small tree.
Sec 29 T65N—R5W   Wabash fine sandy loam.
Infrequent to rare.

Syringa vulgaris L.
W
Cultivated.

GENTIANACEAE

Sabbatia campestris Nutt.
F
Sec 33 T68N—R4W   Lindley loam.
Very rare.

APOCYNACEAE

Apocynum cannabinum L.
F
Sec 22 T68N—R3W   Wabash clay.
Growing in water.

Apocynum medium Greene.
F
Sec 26 T68N—R4W   Marion silt loam.
Infrequent.

ASCLEPIADACEAE

Acerates floridana (Lam.) Hitchc.
FO
Sec 15/22 T66N—R6W   Buckner silt loam.
Sec 19 T65N—R5W   Putnam loam.

Asclepias amplexicaulis Sm.
F
Sec 33 T67N—R5W   Buckner fine sand.
Infrequent.
Asclepias incarnata L.
FB
Sec 2 T66N—R6W   Genesee very fine sandy loam.
Infrequent.
Sec 4 T68N—R3W   Wabash silty clay loam.
Infrequent.
Asclepias purpurascens L.
FWB
Asclepias quadrifolia Jacq.
FOB
Asclepias syriaca L.
F
Sec 20 T68N—R4W   Grundy silt loam.
Common.
Asclepias tuberosa L.
FWB
Sec 19 T65N—R5W   Wabash clay.
Infrequent.
Asclepias verticillata L.
F
Sec 36 T66N—R6W   Marion silt loam.
Infrequent.
Gonolobus laevis Michx.
C

CONVOLVULACEAE

Convolvulus arvensis L.
FW
Sec 13 T66N—R5W   Genesee very fine sandy loam.
Frequent along roads and fences.
Naturalized from Europe.
Convolvulus sepium L.
FW
Sec 17 T65N—R5W   Marion silt loam.
Fairly common.
Cuscuta glomerata Chois.
C
Ipomoea coccinea L.
C
Ipomoea hederacea Jacq.
F
Sec 26 T67N—R6W   Grundy silt loam.
Infrequent.   Introduced from tropical America.
Ipomoea pandurata (L.) G.F.W. Mey.
F
Sec 28 T64N—R4W   Lindley loam.
Frequent.

POLEMONIACEAE

Phlox divaricata L.
FOB
Phlox paniculata L.
O
Phlox maculata L.
O
Polemonium reptans L.
FOB
Sec 14 T66N—R4W

HYDROPHYLLACEAE

Ellisia Nyctelea L.
OWFB
Hydrophyllum appendiculatum Michx.
WCO
Hydrophyllum virginianum L.
FOB

BORAGINACEAE

Cynoglossum officinale L.
FO
Sec 26 T66N—R5W Lindley loam.
Rare in this soil.
Sec 20 T65N—R5W Wabash fine sandy loam.
Infrequent. Naturalized from Europe.
Echium vulgare L.
C
Lappula virginiana (L.) Greene.
F
Sec 24 T67N—R4W Lindley loam.
Infrequent.
Lithospermum Gmelini (Michx.) Hitchc.
O
Mertensia virginica (L.) D.C.
O
Myosotis virginica (L.) B.S.P.

VERBENACEAE

Lippia lanceolata Michx.
F
Sec 4 T68N—R3W Wabash silty clay loam.
Common in wet places.
Sec 1 T65N—R5W Genesee very fine sandy loam.
Frequent in wet soils.
Verbena bracteosa Michx.
FW
Sec 36 T65N—R6W Lindley loam.
Common on railroad ballast.
Verbena stricta Vent.
FW
Sec 6 T68N—R3W Buckner very fine sandy loam.
Pink flowers. Rather rare.
Sec 29 T67N—R5W Buckner very fine sandy loam.
White flowers. Very rare.
Sec 14 T66N—R6W Genesee very fine sandy loam.
Blue flowers. Common in overgrazed pastures.
Verbena urticifolia L.
FB
Sec 33 T67N—R6W Lindley loam.
Infrequent at this date (July 14, 1931).
Sec 28 T68N—R4W Lindley loam.
Frequent at this date (July 21, 1931).

LABIATAE

Agastache nepetoides (L.) Kitze.
C
Blephilia ciliata (L.) Raf.
WB
Blephilia hirsuta (Pursh.) Benth.
FB

Hedeoma hispida Pursh.
F
Sec 28 T64N—R4W Memphis silt loam.
On dry hills under shade.
Sec 36 T66N—R6W Buckner silt loam.
Hedeoma pulegioides (L.) Pers.
F

Lamium amplexicaule L.
CF

Leonurus Cardiaca L.
FW
Sec 3 T65N—R6W Wabash silt loam.
Naturalized from Europe.

Lycopus americanus Muhl.
FC
Sec 30 T68N—R3W Buckner silt loam.
Infrequent.

Lycopus virginicus L.
CB

Marrubium vulgare L.
F
Sec 19 T65N—R5W Putnam loam.
Naturalized from Europe.

Monarda didyma L.
W

Monarda mollis L.
FW
Sec 2 T66N—R6W Genesee very fine sandy loam.
On dry hills.

Monarda punotata L.
F

Nepeta Cataria L.
FW
Sec 2 T66N—R6W Genesee very fine sandy loam.
Infrequent.
Sec 4 T66N—R5W Buckner fine sand.
Frequent. Naturalized from Europe.

Nepeta hederacea (L.) Trevisan
OC

Prunella vulgaris L.
FB

Pycanthemum flexuosum (Walt.) B.S.P.
F
Sec 2 T66N—R6W Marion silt loam.
Frequent.

Pycnanthemum pilosum Nutt.
FB
Sec 28 T68N—R4W Memphis silt loam.
Frequent.

Scutellaria lateriflora L.
F
Sec 30 T68N—R3W Buckner silt loam.
Infrequent.

Scutellaria parvula Michx.
F
Sec 13 T66N—R6W Marion silt loam.
Infrequent. An annual.

Scutellaria versicolor Nutt.
FW
Sec 1 T65N—R5W Memphis loam.
Frequent under maple-hickory shade.

Stachys palustris L.
F
Sec 4 T68N—R3W   Wabash silty clay loam.
Frequent.
Stachys tenuifolia Willd.
F
Sec 30 T68N—R3W   Buckner silt loam.
Frequent.
Teucrium canadense L.
FB
Sec 2 T66N—R6W   Lindley loam.
Frequent in damp ground.

SOLANACEAE

Datura Stramonium L.
F
Sec 14 T68N—R3W   Wabash loam.
Infrequent.   Naturalized from Asia.
Physalis heterophylla Nees.
FW
Sec 33 T67N—R7W   Marion silt loam.
Infrequent.
Physalis lanceolata Michx.
F
Sec 2 T66N—R6W   Marion silt loam.
Rare.
Physalis longifolia Nutt.
F
Sec 28 T64N—R4W   Lindley loam.
Infrequent.
Solanum carolinense L.
FW
Sec 29 T65N—R5W   Wabash fine sandy loam.
Sec 28 T67N—R5W   Buckner fine sand.
Naturalized from the south.
Solanum Dulcamara L.
FB
Introduced from Europe.
Solanum nigrum L.
FB
Sec 28 T67N—R5W   Buckner fine sand.
Frequent.
Solanum rostratum Dunal.
F
Sec 26 T67N—R7W.   Putnam loam.
Infrequent.   Found in a barnyard.
Adventive from the western plains.

SCROPHULARIACEAE

Agalinis tenuifolia (Vahl.) Raf.
FB
   = *Gerardia* of Gray's Manual.
Castilleja coccinea (L.) Spreng.
OC
Dasystoma grandiflora (Benth.) Wood.
   = *Gerardia grandiflora* Benth.
F
Sec 20 T67N—R7W   Union stony loam.
Infrequent.
Gratiola neglecta Torr.
   = *virginiana* L. in part
F

Linaria vulgaris Hill.
FW
Naturalized from Europe.
Otophylla auriculata (Michx.) Small.
 = *Gerardia* of Gray's Manual.
F
Sec 2 T66N—R6W Lindley loam.
Infrequent.
Pentstemon Digitalis (Sweet) Nutt.
 = *P. laevigatus* var. *Digitalis* (Sweet) Gray
F
Sec 33 T68N—R4W Memphis silt loam.
Frequent.
Pentstemon hirsutus (L.) Willd.
 = *P. pubescens* Ait.
OCB
Scrophularia lanceolata Pursh.
 = *S. leporella* Bicknell.
F
Sec 33 T67N—R5W Buckner fine sandy loam.
Infrequent.
Verbascum Blattaria L.
FB
Sec 1 T65N—R5W Memphis silt loam.
Infrequent in shady woods.
Introduced from Europe.
Verbascum Thapsus L.
FWB
Sec 2 T66N—R6W Lindley loam.
Infrequent along roads.
Sec 22 T67N—R5W Buckner loam.
Frequent. Naturalized from Europe.
Veronica arvensis L.
C
Veronica peregrina L.
F
Veronica serpyllifolia L.
C
Veronica virginica L.
F
Sec 24 T68N—R4W Lindley loam.
Frequent.
Sec 2 T66N—R6W Marion silt loam.
Infrequent.

OROBANCHACEAE

Orobanche uniflora L.
C

BIGNONIACEAE

Tecoma radicans DC.
FB
Sec 2 T66N—R6W Lindley loam.
An escape from cultivation.
Catalpa speciosa Warder.
F
Sec 2 T65N—R5W Lindley loam.
Frequent.

MARTYNIACEAE

Martynia louisiana Mill.
C

ACANTHACEAE

Dianthera americana L.
F
Ruellia ciliosa Pursh.
F
Sec 20 T65N—R5W Putnam loam.
Common along roads.

PHRYMACEAE

Phryma Leptostachya L.
F

PLANTAGINACEAE

Plantago aristata Michx.
FW
Plantago lanceolata L.
FW
Naturalized from Europe.
Plantago major L.
W
Plantago Purshii R. & S.
C
Plantago Rugelii Dcne.
F
Sec 23 T66N—R6W Genesee very fine sandy loam.
Sec 24 T68N—R7W Lindley loam.
Common.
Plantago virginica L.
F

RUBIACEAE

Cephalanthus occidentalis L.
FB
Galium Aparine L.
F
Galium concinnum T. & G.
FW
Galium triflorum Michx.
FW
Sec 28 T68N—R4W Memphis silt loam.
Frequent in damp woods.

CAPRIFOLIACEAE

Lonicera dioica L.
O
Sambucus canadensis L.
FW
Symphoricarpos orbiculatus Muench.
W
Symphoricarpos racemosus Michx.
F
Native further north and east.
Triosteum aurantiacum Bicknell.
F
Viburnum Lentago L.
F
Sec 2 T66N—R6W Genesee very fine sandy loam.
Infrequent.
Viburnum prunifolium L.
F

CAMPANULACEAE

Campanula americana L.
FWB
Sec 2 T66N—R6W Lindley loam.
Frequent.
Sec 14 T66N—R6W Genesee very fine sandy loam.
Sec 13 T66N—R5W Genesee very fine sandy loam.
Specularia perfoliata (L.) A. DC.
FW
Lobelia cardinalis L.
C
Lobelia inflata L.
FOB
Sec 29 T68N—R4W
Infrequent.
Lobelia spicata Lam.
W
Lobelia syphilitica L.
FB

COMPOSITAE

Achillea lanulosa Nutt.
F
Native from Saskatchewan to New Mexico and westward.
Achillea Millefolium L.
F
Adventive from Europe.
Ambrosia psilostachya DC.
C
Ambrosia trifida L.
FB
Very common along roads.
Antennaria neglecta Greene.
F
Sec 30 T69N—R3W Lindley loam.
Infrequent.
Antennaria plantaginifolia (L.) Richards.
F
Anthemis Cotula L.
FCW
Sec 19 T65N—R5W Putnam loam.
Very common. Naturalized from Europe.
Arctium minus Bernh.
F
Sec 8 T67N—R5W Marion silt loam.
Frequent. Naturalized from Europe.
Artemisia annua L.
C
Aster azureus Lindl.
C
Aster cordifolius L.
C
Aster Drummondii Lindl.
C
Aster ericoides L.
FC
Aster laevis L.
FCB
Sec 21 T67N—R7W Lindley loam.
Infrequent.

Aster lateriflorus (L.) Britt.
C
Aster lateriflorus (L.) Britt.
  var. *bifrons* (Gray) Fernald.
C
Aster multiflorus Ait.
FB
Frequent.
Aster sagittifolius Wedemeyer.
W
Aster salicifolius Ait.
C
Aster sericeus Vent.
C
Aster Shortii Lindl.
CB
Aster tenuifolius L.
C
Aster Tradescanti L.
F
Sec 13 T65N—R5W Genesee very fine sandy loam.
Bidens bipinnata L.
F
Sec 33 T67N—R5W Buckner fine sand.
Infrequent. First specimen from Iowa to the I.S.C. Herbarium.
Bidens frondosa L.
C
Bidens involucrata (Nutt.) Britt.
F
Sec 36 T67N—R6W Grundy silt loam.
Very common. A bad fall weed.
Brauneria pallida (Nutt.) Britt.
FW
Sec 36 T67N—R6W Lindley loam.
Infrequent.
Centaurea Cyanus L.
W
Introduced from Europe.
Chrysanthemum Leucanthemum L.
F
Sec 26 T67N—R6W Grundy silt loam.
Infrequent. Naturalized from Europe.
Chrysanthemum Parthenium (L.) Bernh.
W
Cirsium altissimum (L.) Spreng.
C
Cirsium discolor (Muhl.) Spreng.
F
Very common.
Cirsium undulatum (Nutt.) Spreng.
F
Sec 21 T67N—R5W Buckner fine sand.
Along railroad. Fairly common.
Coreopsis palmata Nutt.
FW
Sec 29 T65N—R5W Wabash fine sandy loam.
Only one specimen found at this date (June 15, 1932).
Coreopsis tripteris L.
C

Erechtites hieracifolia (L.) Raf.
C

Erigeron annuus (L.) Pers.
W

Erigeron canadensis L.
C

Erigeron ramosus (Walt.) BSP.
F

Eupatorium altissimum L.
F
Sec 11 T66N—R6W   Genesee very fine sandy loam.
Fairly common on creek banks.

Eupatorium purpureum L.
F

Eupatorium serotinum Michx.
F
Sec 20 T65N—R5W   Wabash fine sandy loam.
Infrequent.

Eupatorium urticaefolium Reichard.
F
Frequent.

Gnaphalium purpureum L.
F
Sec 27 T67N—R7W   Genesee silt loam.
Infrequent.   A low annual.

Helenium autumnale L.
FB
Sec 11 T66N—R6W   Genesee very fine sandy loam.
Frequent.

Helianthus annuus L.
F
Sec 33 T68N—R3W   Wabash clay.
Common.

Helianthus doronicoides Lam.
C

Helianthus petiolaris Nutt.
F
Sec 27 T67N—R5W   Buckner loam.
Native of the western plains.
Probably introduced in Iowa.

Helianthus scaberrimus Ell.
W

Helianthus strumosus L.
F
Sec 25 T68N—R4W   Lindley loam.
Frequent.
Sec 28 T68N—R4W   Genesee very fine sandy loam.
Frequent.

Heliopsis helianthoides (L.) Sweet.
F
Sec 4 T66N—R7W   Buckner very fine sandy loam.

Krigia amplexicaulis Nutt.
   (*Cynthia virginica* (L.) D. Don.)
F
Sec 9 T65N—R5W   Lindley loam.
Rare.

Kuhnia eupatorioides L.
F
Sec 28 T67N—R5W   Buckner fine sand.
Infrequent.

Lactuca canadensis L.
FC
Sec 4 T66N—R7W Buckner very fine sandy loam.
Sec 20 T68N—R4W Grundy silt loam.
Common.
Sec 2 T65N—R5W Lindley loam.
Lactuca floridana (L.) Gaertn.
C
Lactuca scariola L.
F
Sec 4 T66N—R7W Buckner very fine sandy loam.
Very common. Naturalized from Europe.
Lactuca villosa Jacq.
F
Blue flowers.
Lepachys pinnata (Vent.) T. & G.
CF
Leptilon canadense (L.) Britt.
  = *Erigeron canadensis* L.
F
Sec 8 T65N—R5W Marion silt loam.
Infrequent.
Leptilon divaricatus Michx.
F
Sec 27 T67N—R7W Genesee silt loam.
Frequent in low ground.
Sec 14 T67N—R5W Buckner very fine sandy loam.
Frequent in bottomland soils.
Liatris cylindracea Michx.
C
Liatris pycnostachya Michx.
FB
Sec 24 T66N—R6W Marion silt loam.
Liatris scariosa Willd.
FB
Frequent on upland soils.
Parthenium integrifolium L.
FWB
Sec 36 T66N—R6W Marion silt loam.
Infrequent.
Sec 8 T65N—R5W Marion silt loam.
Frequent on upland soils.
Polymnia canadensis L.
W
Prenanthes alba L.
F
Infrequent.
Prenanthes aspera Michx.
C
Rudbeckia hirta L.
FWB
Sec 29 T65N—R5W Wabash fine sandy loam.
Only one specimen at this date (June 25, 1932).
Sec 17 T65N—R5W Putnam loam.
Frequent.
Rudbeckia subtomentosa Pursh.
C
Rudbeckia triloba L.
FB
Sec 26 T66N—R5W Genesee silt loam.
Infrequent.

Silphium integrifolium Michx.
F
Sec 6 T66N—R6W Genesee very fine sandy loam.
Frequent.
Silphium laciniatum L.
FB
Sec 1 T66N—R6W Putnam loam.
Infrequent.
Silphium perfoliatum L.
FB
Sec 36 T66N—R6W Marion silt loam.
Infrequent to common.
Solidago canadensis L.
C
Solidago latifolia L.
C
Solidago rigidiuscula Porter.
  = *S. speciosa* var. *angustata* T. & G.
F
Solidago serotina Ait.
F
Frequent.
Solidago speciosa Nutt.
CB
Solidago tenuifolia Pursh.
CB
Sonchus oleraceus L.
WC
Tanacetum vulgare L.
F
Sec 20 T65N—R5W Wabash fine sandy loam.
A frequent escape along fences.
Taraxacum erythrospermum Andrz.
F
Taraxacum officinale Weber.
W
Vernonia altissima Nutt.
Sec 20 T68N—R3W Wabash loam.

DISCUSSION OF THE SURVEY

Herbaceous Plants

This survey showed that of the 648 species known to occur in Lee County, 550 of them were herbaceous plants. Of this number, 337 species belonged to the ten most common families as follows: 64 grasses (*Gramineae*), 58 composites (*Compositae*), 44 sedges and rushes (*Cyperaceae* and *Juncaceae*), 35 species in the pea family (*Leguminosae*), 23 species in the rose family (*Rosaceae*), 21 mints (*Labiatae*), 18 buckwheats (*Polygonaceae*), 16 buttercups (*Ranunculaceae*), 16 mustards (*Cruciferae*), 15 species in the lily family (*Liliaceae*), 13 in the carrot family (*Umbelliferae*), and the same number in the figwort family (*Scrophulariaceae*).

In the grass family there was a wide variety of species scattered through 35 genera. Some of the more common ones were Alopecurus along roadsides, Cenchrus in sandy fields and railroad ballast, Digitaria often a pest in cornfields, Elymus species along roads, Hystrix in dense shady woods, Panicum species in uplands and bottomlands, Poa species in pastures where the shade was moderate, and Setaria along the edges of fields and roads. Some of the genera, which were rare were Aristida and Bouteloua

in the Mississippi bottom northeast of Fort Madison, Calamagrostis on the upland soils, Danthonia along the top of the Des Moines bluffs, Diarrhena in the hilly sections near Argyle, and Triplasis in the sandy soils between Montrose and Fort Madison.

Some of the most abundant genera of the composite family (*Compositae*) were Achillea in the hilly sections, Ambrosia along roads and creeks and in wet bottomlands, Anthemis which is abundant in the hill sections June 15 to August 1, and Bidens, a troublesome and abundant weed in September, in upland and hill sections. Erigeron is another genus which was abundant in June and July. Lactuca species were common along railroad tracks and Silphium was common in the bottomlands. Vernonia was a common summer pasture weed. The uncommon genera were Brauneria, Chrysanthemum, Gnaphalium and Krigia.

The most abundant sedges (*Cyperaceae*) in uplands, hills and bottomlands, were species of Carex although Eleocharis was probably the most common genus in wet or swampy bottomlands. Scirpus species were commonly found in wet roadside ditches in the hill and upland sections. Some of the rarest sedges were *Carex Asa-Grayi* in the undrained bottom northeast of Fort Madison and *Scirpus americanus* along a railroad track near New Boston.

Trees and Shrubs

The available data show that 97 species of trees and shrubs occur in Lee County of which 56 are trees and 41 shrubs; 68 species were collected by this survey, 18 by Professor H. E. Jaques, and 20 by other collectors.

One tree and one shrub new to Iowa were found in this survey, as follows:

1. An oak hybrid (*Quercus marilandica* x *Quercus velutina* = *Quercus Bushii* Sarg.)
2. Black Haw (*Viburnum prunifolium* L.)

The oak hybrid was found only once in a grove of Black Jack Oak near Summit School and the Black Haw was found along the Mississippi bluffs, south of Montrose, on a shady, damp, east exposure.

Five other species and one variety which are particularly characteristic of Lee County and southeastern Iowa were found. The one species particularly adapted to Lee County was the Papaw which was found exclusively and in abundance along the warm, damp Mississippi bluffs above Keokuk. It is found mostly further south and east, in Illinois, etc. The Ohio Buckeye (*Aesculus glabra* L.) and its variety (*A. glabra* var. *arguta*) were found along the bluffs below Montrose. Both of these are found native in the extreme southern counties although there is one station of the species as far north as Boone county. The Hop Tree or Wafer Ash (*Ptelea trifoliata* L.) occurred mostly in sandy bottoms along the Des Moines. It is further distributed in Iowa along the Mississippi to Scott County and west to Wapello although there is one specimen from Cass county in the Iowa State College Herbarium. The Red Bud (*Cercis canadensis* L.) was found growing vigorously along the Des Moines River. It is native from Lee county to Muscatine and as far west as Mills county. In Illinois it is

well distributed except in the northwest corner of the state. The Overcup Oak (*Quercus lyrata*) has been recorded by Dr. L. H. Pammel from a single station north of Keokuk. Otherwise it is known only in Appanoose county. In Illinois it has only been found in the southern quarter of the state. There are many other species of trees and shrubs in Lee county but they are either widely distributed in Iowa or not particularly abundant.

Plant Indicators

From an examination of the field notes and from field experience, it seems that the plants of Lee County are either sub-specific or quite general in their local soil requirements. Many of the plants of sandy, sandy loam, and clay soils were found to be relatively specific while most of the species on silt loam, and loam soils were very general in their requirements.

It was found that *Cenchrus pauciflorus, Cycloloma atriplicifolium, Polanisia trachysperma, Sporobolus cryptandrus, Cyperus esculentus,* and *Cyperus Schweinitzii* were good indicators of sandy areas.

Typha latifolia, Eleocharis acicularis, Eleocharis palustris, Hibiscus militaris, Carex lupulina and *Anemone canadensis* were particularly characteristic of the clay soils northeast of Fort Madison. *Phytolacca decandra* is a very large shrub-like herb that was found only once along the Mississippi in this area.

The largest number of species found on any one soil type was 120 on the silt loam soils. *Abutilon Theophrasti, Bidens involucrata, Cassia Chamaecrista, Leptilon canadense, Panicum capillare, Scirpus atrovirens* and *Ulmus americana* seemed to be the best indicators.

The number of species on the loam soils was practically the same as on the silt loam types (117 species). The most common species were *Baptisia bracteata, Carex vulpinoidea, Daucus Carota, Digitaria sanguinalis, Elymus robustus, Hibiscus Trionum, Malus ioensis, Prunus serotina, Quercus alba* and *Rhus glabra.*

The commonest species of the flora on the sandy loams in the bottom-lands were such species as *Agropyron repens, Amaranthus blitoides, Cyperus filiculmis, Eragrostis hypnoides, Leptilon divaricatum, Monarda mollis, Polanisia trachysperma,* and *Verbena stricta.*

The flora of the stony loam soils near Croton and northeast of Denmark was very limited but distinctive. *Dasystoma grandiflora* and *Steironema ciliatum* were the most characteristic species.

The higher yearly average temperature and precipitation as compared to the rest of Iowa[6] was reflected in the flora by the presence of such species as *Allium mutabile, Commelina virginica, Elymus glabriflorus, Gnaphalium purpureum, X Quercus Bushii,* and *Viburnum prunifolium* which have not been found in Iowa before as far as known. Two of these, *Allium mutabile,* and *Gnaphalium purpureum* are at the northern limits of their ranges in Lee County, while the other five species are well within their ranges and will probably be found later at other stations in the state.

The Papaw (*Asimina triloba*) is another species which, although found in Des Moines and Fremont counties, is particularly adapted to the local

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[6] There were no available data on soil moisture in Lee County, but from United States Weather Bureau records (data from July 15, 1871, to December 31, 1908) it was found that the annual mean precipitation at Keokuk was 35.1 inches as compared to 32.4 at Des Moines. The mean annual temperature was 3°F. higher and the minimum January temperatures 10°F. higher at Keokuk.

conditions along the Mississippi bluffs above Keokuk where the precipitation and temperature are very similar to those further south and east.

SUMMARY

1. A systematic list of the 645 known species of flowering plants of Lee County, Iowa, was made of which 456 species were collected and identified by this survey; 92 species by the late Dr. Ehringer of Keokuk, Iowa, whose specimens are now in the Carthage College Herbarium, Carthage, Illinois; 87 species by Professor H. E. Jaques, Iowa Wesleyan, Mt. Pleasant, Iowa; 87 species by Mrs. Kate O'Bleanus of Lee County, Iowa; and 17 species by various collectors whose plants were in the Iowa State College Herbarium prior to June 15, 1931.

2. It was found that 333 species of the 645 were contained in the ten largest families as follows: *Gramineae* 63, *Compositae* 58, *Cyperaceae* and *Juncaceae* 44, *Leguminosae* 35, *Rosaceae* 23, *Labiateae* 21, *Polygonaceae* 19, *Ranunculaceae* 15, *Cruciferae* 16, *Liliaceae* 15, *Umbelliferae* 13, and *Scrophulariaceae* 13.

2. A total of 97 species of trees and shrubs were recorded.

4. One tree X *Quercus Bushii*, and one shrub, *Viburnum prunifolium*, were recorded the first time for Iowa. These two species and *Asimina triloba*, *Aesculus glabra*, *Aesculus glabra* var. *arguta*, *Petelea trifoliata*, *Cercis canadensis*, and *Quercus lyrata* were found to be the most distinctive species of Lee county and southeastern Iowa.

5. An unusual number of *Quercus* species was found which were as follows: *Quercus alba*, *Quercus bicolor*, *Quercus imbricaria*, *Quercus macrocarpa*, *Quercus marilandica*, *Quercus maxima*, *Quercus Muhlenbergii*, *Quercus palustris*, *Quercus rubra*, *Quercus stellata*, *Quercus velutina*, and X *Quercus Bushii* (*Quercus velutina* x *marilandica*).

6. Practically all the plants collected by this survey were listed according to the soil type on which they occurred. From this list and field experience it was found that the flora on sandy and clay soils was made up of a much smaller number of species than the loam, silt loam or sandy loam soils, but was more definitely characteristic.

7. The most characteristic species of *sand soil* were found to be *Cenchrus pauciflorus*, *Cycloloma atriplicifolium*, *Polanisia trachysperma*, *Sporobolus cryptandrus* and *Cyperus esculentus*; those of *clay* soils were *Typha latifolia*, *Eleocharis palustris*, *Eleocharis acicularis*, *Hibiscus militaris*, *Carex lupulina* and *Anemone canadensis*; those of *silt loams* were *Abutilon Theophrasti*, *Bidens involucrata*, *Cassia Chamaecrista*, *Leptilon canadensis*, *Panicum capillare*, *Scirpus atrovirens* and *Ulmus americana*; those of *loam soils* were *Baptisia bracteata*, *Carex vulpinoidea*, *Daucus Carota*, *Digitaria sanguinalis*, *Elymus robustus*, *Hibiscus Trionum* and *Quercus alba*; those on *sandy loams* were *Agropyron repens*, *Amaranthus blitoides*, *Cyperus filiculmis*, *Eragrostis hypnoides*, *Leptilon divaricatum*, and *Polanisia trachysperma*; and those on *stony loams* were *Dasystoma grandiflora* and *Steironema ciliatum*.

9. The more favorable temperature and precipitation conditions of the county as compared to the rest of Iowa are reflected in the flora by the presence of such species as *Allium mutabile*, *Commelina virginica*, *Elymus glabriflorus*, *Gnaphalium purpureum*, X *Quercus Bushii*, *Viburnum prunifolium*, and *Asimina triloba* which, with the exception of the last, probably occur in Iowa exclusively in Lee County.

LINKAGE DATA ON THE R-g₁ CHROMOSOME OF MAIZE[1]

J. B. WENTZ AND S. N. SMITH

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The corn plant has been more completely analyzed genetically than any other plant species. Through the individual and co-operative efforts of geneticists working with maize, approximately 300 genes have been studied and ten linkage groups have been established. The R-g₁ group gets its designation from the fact that R, a factor for aleurone color, and g₁, a factor causing golden plants, were the first genes found to be in this group.

In 1930 Dr. R. A. Emerson and his associates at Cornell University compiled all the linkage data available on maize and distributed a mimeographed report showing the linkage groups as they had been built up to that time. At that time the R-g₁ group contained 14 genes, some of which had been definitely located on the chromosome.

The present paper presents linkage data on the R-g₁ chromosome collected by the authors since the report of Emerson and his associates in 1930.

SUMMARY OF DATA

Table 1 presents a summary of the data on all characters studied and indicates whether the linkages are in the coupling or repulsion phase. Following the table there is a list of the gene symbols used together with the characters of the plant or seed affected by these genes.

All the data in table 1 are from F_2 progenies. All seedling counts were made in the greenhouse including golden plants. Wherever gm₂ is involved the percentages of recombination were necessarily determined from the proportion of normal and abnormal seedlings grown from normal seeds taken from ears segregating for germless seeds. This makes it necessary to determine the linkage relations by the use of only two phenotypic classes. In most cases where two seedling characters are involved only three phenotypes could be distinguished.

Where only two or three phenotypic classes were available the percentage of recombinations was determined by reducing the numbers to percentages and making comparisons in Owen's tables (6). The numbers obtained by use of Owen's tables were further checked by use of a formula suggested by Collins (1). In the one case where all four phenotypes could be distinguished Emerson's formula (2) was used to calculate the gametic ratio and the corresponding crossover value was checked by Immer's tables (3).

TABLE 1.   *Summary of linkage data on the E-g₁ chromosome*

Genes XY	Linkage phase	Number of individuals					Percentage recomb.
		XY	Xy	xY	xy	Total	
Gm₂G₁	Coupling	4402	1335			5737	44.8
Gm₂Pg₁	Coupling	3552	1023			4575	42.6
Pg₁G₁	Coupling	2519	325	332	626	3802	19.2
Gm₂L₂	Repulsion	1958	560			2518	50.0
Gm₂L₄	Repulsion	1799	625			2424	50.0
G₁L₂	Repulsion	2957	1011	1409		5377	48.0
G₁L₄	Repulsion	2525	991	1292		4808	39.0
Pg₁L₄	Repulsion	1303	521	632		2456	37.0
Pg₁L₂	Coupling	1725	531	758		3014	46.0

List of gene symbols

Gm₂ gm₂—Germless seeds
Pg₁ pg₁—Pale green seedlings
L₂ l₂—Yellow seedlings
L₄ l₄—Yellow seedlings
G₁ g₁—Golden plants

DISCUSSION

Each of the linkages reported in table 1 will be discussed separately along with any explanatory notes which seem necessary.

gm_2 and g_1

In an earlier paper Wentz (7) reported independent inheritance of these two genes. In the earlier paper, however, the data were on the repulsion phase and were not so extensive. It is entirely possible that the low linkage value shown in table 1 would not be indicated in the repulsion data.

On the basis of the 44.8 per cent of recombinations the gametic ratio would be 1.23:1. Table 2 shows the observed numbers of normal and golden plants and the numbers calculated on the basis of the 1.23:1 gametic ratio.

TABLE 2.   *Observed and calculated numbers of normal and golden plants on the basis of a gametic ratio of 1.23:1*

	Normal	Golden	Total
Observed	4402.00	1335.00	5737
Calculated	4406.59	1330.41	5737
Deviation	—4.59	+4.59	

For comparison, seed was planted from ears from the same progenies but which were not segregating for germless seeds. The numbers of normal and golden plants obtained from these ears were 4,897 and 1,633 respectively. This is an excess of just 0.5 golden plants. This indicates that the shortage of golden plants from the ears segregating for gm₂ must have been due to linkage of the g₁ factor with the lehtal gm₂ factor.

gm_2 and pg_1

Earlier F₂ repulsion data (7) gave only a slight indication of linkage between these two factors. The coupling data in table 1 indicate quite definitely that there is a loose linkage between the two genes. The 42.6 per cent of recombinations corresponds to a gametic ratio of 1.35:1 and

the numbers of normal and pale green seedlings calculated on this basis fit the observed numbers very closely as seen in table 3.

TABLE 3.   *Observed and calculated numbers of normal and pale green seedlings on the basis of a gametic ratio of 1.35:1*

	Normal	Pale green	Total
Observed	3552.00	1023.00	4575.00
Calculated	3552.95	1022.05	4575.00
Deviation	+0.95	—0.95	

When seed was planted from ears not segregating for gm_2 the ratio of normal to pale green seedlings was 3,728 to 1,190. This is a shortage of 39.5 pale green seedlings as compared to a probable error of 20.48. This is a fair fit indicating that the large shortage of pale green seedlings from the ears segregating for gm_2 was no doubt due to linkage between the genes causing germless seeds and pale green seedlings.

pg_1 and g_1

Less extensive data published by the senior author (7) in 1930 showed a recombination percentage of 14.5 in the coupling phase. This is reasonably close to the 19.2 per cent shown in table 1. The gametic ratio corresponding to 19.2 per cent of recombinations is 4.23:1. The observed number in each of the F_2 phenotypes is shown in table 4 as compared to the numbers calculated on the basis of the gametic ratio of 4.23:1. It will be seen that the calculated numbers fit the observed numbers very closely giving a P value of .95.

TABLE 4.   *Observed and calculated numbers in each phenotypic class calculated on the basis of a gametic ratio of 4.23:1*

	Pg_1G_1	pg_1G_1	Pg_1g_1	pg_1g_1	Total
Observed	2519.00	325.00	332.00	626.00	3802.00
Calculated	2519.96	329.25	329.25	623.54	3802.00
Deviation	—.96	—4.25	+2.75	+2.46	

$$X^2 = .0878$$
$$P = .95$$

gm_2 and l_2

The data in table 1 show a small deficiency of l_2 seedlings while linkage in the repulsion phase should have caused an excess of l_2 seedlings. When seed was planted from ears not segregating for gm_2 the ratio of normal to yellow seedlings was 3,352 to 1,080. This is a deficiency of 28 yellow seedlings which is not quite as large a deficiency as observed from the ears segregating for gm_2.

The data in table 1 do not show evidence of linkage between gm_2 and l_2. This is surprising as previous data on gm_2 by Wentz (7) and on l_2 by Jenkins and Bell (4) and Lindstrom (5) place gm_2 and l_2 both to the left of R. Dr. R. A. Emerson who is preparing a new summary of the linkage groups has reported, by correspondence with the senior author,

other irregularities in the R-g_1 group. There may be some peculiarity about the structure of the R-g_1 chromosome.

gm_2 and l_4

The numbers in table 1 show a slight excess of yellow seedlings but hardly enough to suggest linkage. The deviation from the expected number of yellow seedlings on the basis of independent inheritance is only 19 with a probable error of 14.37.

When seed was planted from ears not segregating for gm_2 the ratio of normal to yellow seedlings was 1,113 to 393. Here there is an excess of 16.5 yellow seedlings with a probable error of 11.32.

g_1 and l_2

The data on g_1 and l_2 fit fairly well the numbers expected on the basis of independent inheritance as shown in table 5. Here the value of P is .10.

TABLE 5. *Observed and calculated numbers in each phenotypic class on the basis of independent inheritance*

	Observed	Calculated	Deviation
G_1L_2	2957	3024.56	—67.56
g_1L_2	1011	1008.19	+ 2.81
$G_1l_2+g_1l_2$	1409	1344.25	+64.75

$$X^2 = 4.6358$$
$$P = .10$$

The shortage of normal green plans with the very slight excess of golden plants might indicate a small amount of linkage. When the theoretical numbers are calculated on the basis of 48 per cent of recombinations or a gametic ratio of 1 : 1.08 they fit the observed numbers a very little closer than when independent inheritance is assumed. Table 6 compares the observed and theoretical numbers calculated on the basis of the 1 : 1.08 gametic ratio.

TABLE 6. *Observed and calculated numbers in each phenotypic class calculated on the basis of a gametic ratio of 1:1.08*

	Observed	Calculated	Deviation
G_1L_2	2957	2999.21	—42.21
g_1L_2	1011	1033.54	—22.54
$G_1l_2+g_1l_2$	1409	1344.25	+64.75

$$X^2 = 4.2920$$
$$P = .10$$

It will be noted that the fit would have been much closer except for the rather large excess of yellow seedlings. This excess of yellow seedlings can be largely accounted for by the fact that the yellow seedling counts were made about three weeks earlier than the green and golden counts. The golden plants cannot be classified satisfactorily until they are 12 to 15 inches tall. There was no doubt some loss of plants by injury and dis-

ease between the time the yellow seedlings were counted and the time that the green and golden plants were counted.

When the yellow seedlings are disregarded the numbers of green and golden plants observed fit very closely the numbers calculated on the basis of the gametic ratio of 1 : 1.08 as shown in table 7.

TABLE 7. *Observed and calculated numbers of green and golden plants on the basis of a gametic ratio of 1:1.08*

	Observed	Calculated	Deviation
G_1L_2	2957	2951.05	+5.95
g_1L_2	1011	1016.95	—5.95

g_1 and l_4

The observed numbers in table 1 indicate linkage in the repulsion phase. By reducing the numbers to percentages and comparing them in Owen's tables it is found that they come nearest fitting the percentages corresponding with 39 per cent of recombinations. This is a gametic ratio of 1 : 1.56. When the theoretical numbers are calculated on the basis of this gametic ratio they compare with the observed numbers as shown in table 8.

TABLE 8. *Observed and calculated numbers in each phenotypic class calculated on the basis of a gametic ratio of 1:1.56*

	Observed	Calculated	Deviation
G_1L_4	2525	2587.42	—62.42
g_1L_4	991	1018.59	—27.59
$G_1l_4+g_1l_4$	1292	1202.00	+90.00

$$X^2 = 8.9916$$
$$P = .01$$

The value of P in table 8 is only .01. It can be seen, however, that the big deviation is in the third class which consists of G_1l_4 and g_1l_4 seedlings. There is an excess of the yellow seedlings. This excess can at least partly be accounted for by the fact that the counts on normal green and golden plants were necessarily made after the plants were 12 to 15 inches tall while the counts on yellow seedlings were made when the seedlings were still small. There no doubt was some loss of plants through injury and disease between the time the yellow seedlings were counted and the time that the counts were made on green and golden plants. In order to eliminate this possible error the theoretical numbers of green and golden plants were calculated disregarding the yellow seedlings. Table 9 shows that the fit is very close when the yellow seedlings are disregarded.

TABLE 9. *Observed and calculated numbers of green and golden plants on the basis of a gametic ratio of 1:1.56*

	Observed	Calculated	Deviation
G_1L_4	2525	2522.83	+2.17
g_1L_4	991	993.17	—2.17

pg_1 and l_4

The data on pg_1 and l_4 indicate linkage in the repulsion phase. By comparison in Owen's tables we find that the recombination percentage must be about 37. This is a gametic ratio of 1 : 1.7. When the theoretical numbers are calculated on the basis of this gametic ratio they fit the observed numbers very closely as shown in table 10 where the value of P is .70.

TABLE 10. *Observed and calculated numbers in each phenotypic class on the basis of a gametic ratio of 1:1.7*

	Observed	Calculated	Deviation
Pg_1L_4	1303	1212.23	— 9.23
pg_1L_4	521	529.78	— 8.78
$Pg_1l_4+pg_1l_4$	632	614.00	+18.00

$$X^2 = .7381$$
$$P = .70$$

pg_1 and l_2

The data on pg_1 and l_2 fit reasonably well the numbers expected on the basis of independent inheritance. Table 11 shows the value of P to be .30 when the observed numbers are compared with the numbers calculated on the basis of independent inheritance.

TABLE 11. *Observed and calculated numbers in each phenotypic class on the basis of independent inheritance*

	Observed	Calculated	Deviation
Pg_1L_2	1725	1695.38	+29.62
pg_1L_2	531	565.13	—34.13
$Pg_1l_2+pg_1l_2$	758	753.50	+ 4.50

$$X^2 = 2.6075$$
$$P = .30$$

Although the observed numbers are close to those calculated on the basis of independent inheritance it can be seen that the deviations present are in the right direction to indicate a low linkage value in the coupling phase. Table 12 was prepared to compare the observed numbers with calculated numbers on the basis of a low linkage. A recombination value of 46 per cent was assumed. This is a gametic ratio of 1 : 1.17. The numbers calculated on this basis fit very closely the numbers observed. The value of P is .98.

TABLE 12. *Observed and calculated numbers in each phenotypic class on the basis of a gametic ratio of 1:1.17*

	Observed	Calculated	Deviation
Pg_1L_2	1725	1726.04	—1.04
pg_1L_2	531	534.45	—3.45
$Pg_1l_2+pg_1l_2$	758	753.50	+4.50

$$X^2 = .0498$$
$$P = .98$$

SUMMARY AND CONCLUSIONS

In this paper linkage data are presented on five genes previously found to be located on the R-g_1 chromosome.

In the main these data substantiate the relative positions of the genes on the chromosome as summarized by Emerson and his associates in 1930. There is, however, one decided inconsistency. Data presented here on the linkage relations of gm_2 with pg_1 and g_1, and previous data on gm_2 and R, place gm_2 at the left end of the chromosome and since previous data place l_2 and l_4 at opposite ends of the chromosome there should be linkage between gm_2 and either l_2 or l_4. At the present time there is no way of explaining this lack of agreement in the relative positions of the genes. It is hoped that further data bringing in other genes on the chromosome will afford some solution.

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IRREGULAR SPOROGENESIS AND POLYEMBRYONY IN SOME LEGUMINOSAE

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The prevalence in species of Angiosperms of irregularities in meiosis, polymorphism in spores, multiple embryo sacs, or polyembryony is commonly regarded as indicative of a hybrid constitution. Since plants so constituted are generally quite variable in many of their features, they are usually not dependable as to types but are inviting of improvement by selection and other breeding methods. Any disclosures, therefore, pertaining to the constitution of crop plants as important as the clovers and alfalfa are worthy of consideration.

Although the features herein considered pertain especially to *Trifolium pratense* L., *T. repens* L., *Melilotus alba* Des., *Medicago sativa* L., and *Vicia americana* Muhl. of the family Leguminosae, they are probably as prevalent in other species of the family but have escaped notice owing to limited morphological studies.

In *Melilotus alba* two types of pollen (fig. 5), the larger of which was commonly multinucleate and several times the size of the normal type, were observed by Rogers (8) and Castetter (1). The study of the development of the giant pollen grains furnished considerable evidence that they were tetrads in which the division walls had been omitted.

The origin of the embryo sac directly from the mother cell, a method characteristic of the Lily family, has been reported to occur in *Melilotus alba* by Guignard (2) and Young (9) and in *Medicago arborea* by Guignard (2) and Hèrail (3), whereas, in *Melilotus alba* and in the Grimm and common varieties of *Medicago sativa* the senior writer (5, 6) and Reeves (7) found that the embryo sacs in the ovules observed were the products of one megaspore as is customary in Dicotyledons. Although these discrepancies may be due to errors in observation, marked variations in the forming of embryo sacs would be in accord with the other irregularities prevalent in the ovules of these species.

Much variation in the number of mother cells per ovule (figs. 1, 4, 7, 8, and 9) have been observed in *Trifolium pratense, T. repens, Medicago sativa, Melilotus alba,* and *Vicia americana* by the senior author (6). Multiple tetrads of megaspores were noted in all the species, and occasionally in *Melilotus alba* and *Medicago sativa* two or more embryo sacs in the process of development in the same ovule were observed (figs. 1 and 4). The other extreme in which the ovules form no mother cells was found to occasionally occur in *Trifolium pratense*. Several mother cells and as many as three embryo sacs in the same ovule in process of development were observed by Reeves (7) in both the Grimm and common strains of alfalfa.

The development that several embryo sacs in the same ovule may attain and the possibility of two or more of them functioning have received very little attention in the legumes. Jönsson (4) reported polyembryony in

Trifolium pratense. How the embryos were formed was not ascertained, but in view of the tendency of *Trifolium pratense* to form multiple mother cells, it is quite plausible that they were the products of separate embryo sacs.

OBSERVATIONS ON POLYEMBRYONY IN ALFALFA AND SWEET CLOVER

In some experiments on the germination of alfalfa seeds[1] at Iowa State College in 1930 one seed with two radicles protruding was discovered (fig. 2). The removal of the testa revealed two separate, perfect embryos equal in size. They were oppositely oriented and one cotyledon of each embryo was enclosed between the cotyledons of the other (fig. 3.) The axes of the hypocotyls and radicles, although oppositely oriented, were parallel except for the slight opposite curving of the tips of the radicles. The position and orientation of the embryos with reference to the micropyle were very similar and corresponded to the relative position and orientation of multiple embryo sacs in ovules. There was considerable evidence that the embryos were products of separate embryo sacs.

Owing to the close fitting together of their cotyledons, the two embryos did not require much extra space and their presence in the dormant seed was probably scarcely manifest in the size and shape of the seed.

Morphological studies of the seeds of *Melilotus alba* at Iowa State College have occasionally disclosed, in addition to the normal embryo, other structures suggestive of aborted embryos. A case in which polyembryony was quite evident is shown in figure 6 which represents a section of a seed more than half mature with one normal and one miniature embryo in an early stage of differentiation. The secondary embryo, excepting its arrested development, was apparently normal, for it was typical of normal embryos at certain stages in their early development. It was terminal on a suspensor that was nearly normal in type. It occupied an area that resembled an embryo sac and that was separate from the embryo sac of the primary embryo. The two embryos and areas occupied by them were similarly located and oriented in the seed. Their location and orientation corresponded to those of multiple embryo sacs in an ovule. The zygotic origin of both embryos was, therefore, indicated by both morphological and circumstantial evidence.

DISCUSSION

In the ovules of the legumes included in this article the nucelli are slender, seldom more than five or six layers of cells in thickness through the sporogenous region. The competition, therefore, for space as well as for food and water among multiple mother cells or embryo sacs must be exceedingly severe, the result being that all but the survivor usually succumb early in the struggle. In case a parity in competition between a number of mother cells or embryo sacs in an ovule occurs and persists, the situation is much more favorable to the abortion of all mother cells or embryo sacs than to the normal development of two or more of them. The early establishment and maintenance thereafter of a parity in competition between two embryo sacs that permits the normal development of two embryos in the same ovule, as in the polyembryonate alfalfa seed, must be extremely rare. A condition of multiple mother cells or embryo sacs in ovules is therefore

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[1] The seeds were brought from Montana by the junior author. They were claimed to be Grimm but origin and strain were not definitely known.
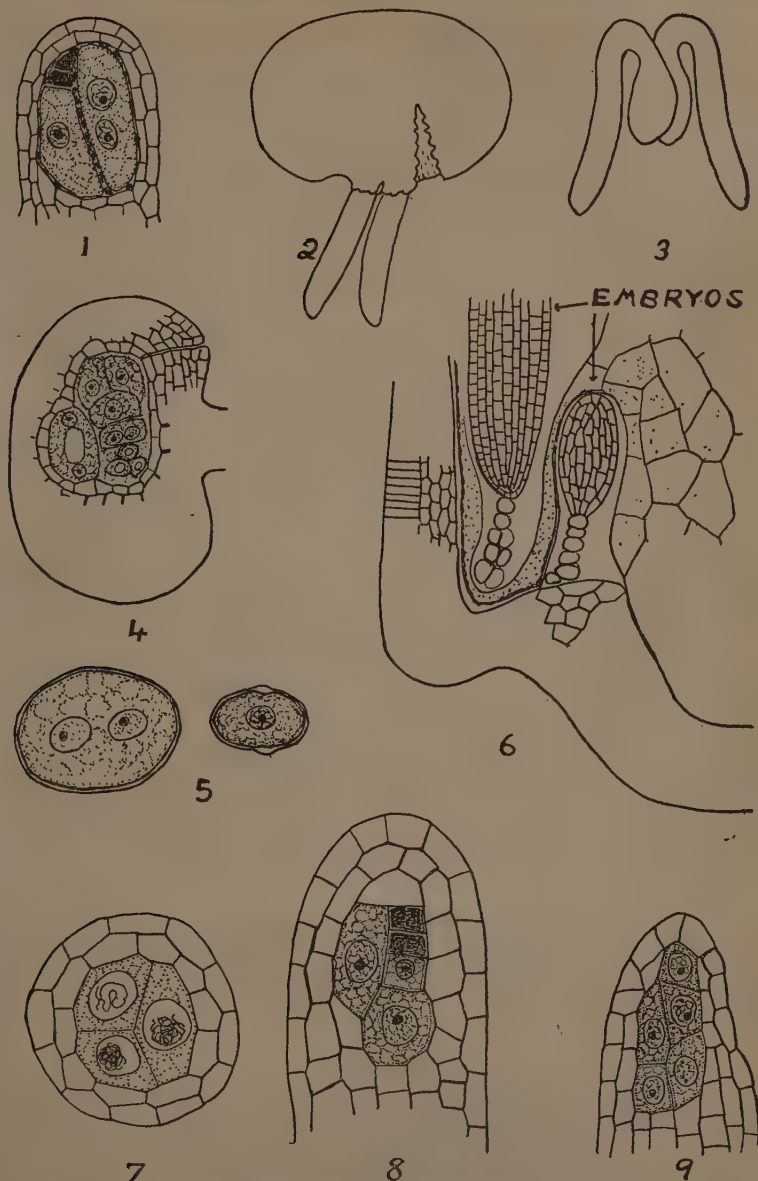
DESCRIPTION OF FIGS. 1-9.

1. Lengthwise section of ovule of *Medicago sativa* showing one megaspore and one two-nucleate embryo sac. 2. Polyembryonate seed of alfalfa showing the two radicles protruding. 3. The relative positions of the two embryos in seed shown in 2. 4. Length-wise section of ovule of *Melilotus alba* showing two embryo sacs in process of development. 5. Two types of pollen in *Melilotus alba*. 6. Lengthwise section of an immature seed of *Melilotus alba* showing two embryos. 7. Three mother cells shown in the cross

usually so obscured by later growth that traces of it in the mature seed are only detectable by microscopical studies.

Owing to the delicacy in the technique required in the study of sporogenesis and the development and functioning of embryo sacs, the number of ovules and especially the number of plants included are relatively small. Consequently, irregularities of common occurrence in the reproductive processes in both anthers and ovules may escape notice. It is quite probable, therefore, that further studies will show that the nucelli of these and other species of legumes are generally arenas where mother cells and embryo sacs compete for supremacy with the result that traces of more than one embryo in a seed is a common occurrence. The frequency of multiple mother cells and embryo sacs in the ovules of the few species investigated favor such a prediction.

Some features in connection with seed production in the clovers, alfalfa, and vetch may be related to the irregularities in the ovules previously described.

In most, if not all, cultivated legumes the abortion of ovules is a common occurrence. In the five species included in this discussion, the abortion of ovules that regularly occurs ranges from 50 per cent in red clover to 80 per cent or more in sweet clover. This regular abortion of ovules which is manifested in their resorption soon after fertilization is apparently a result of competition between ovules.

In addition to this regular abortion of ovules there are other disturbances in seed production that may be due to irregularities within the ovules. Throughout the middle states the average yield of red clover seed is about one-twelfth of the seed production capacity of red clover plants. Most of this failure to produce seed is due to insufficient pollination, but some of it is probably due to failure of ovules to produce mother cells and to competition between mother cells or embryo sacs that interferes with the normal development of ovules and seeds. The dropping of the flowers and young pods so common in sweet clover and alfalfa may be in part due to these irregularities in the ovules, the seriousness of their effects depending upon environmental conditions. Similar causes, may in part be responsible for the common occurrence in alfalfa of seeds with no or only partially developed embryos. In *Vicia americana* the failure of ovules to become seeds is apparently associated with an early disintegration of embryo sacs, a phenomenon that may be traceable to an innate tendency toward irregularities in the ovules.

Although the tendency toward irregularities within the ovules has not been shown definitely to contribute to the failure of seed production in the legumes, it certainly deserves consideration in a program of developing better seed producing plants, an achievement very much needed in red clover and alfalfa.

SUMMARY

1. Two types of pollen in *Melilotus alba* and the tendency of *Trifolium pratense, T. repens, Melilotus alba, Medicago sativa* and *Vicia americana* to produce multiple mother cells and embryo sacs are discussed.

2. Polyembryony in *Medicago sativa* and *Melilotus alba* is described.

3. The probable relation of the irregularities in the reproductive processes to seed production in these legumes is discussed.

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NOTES ON THE IMMIGRANT FLORA OF IOWA, I

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In the year 1929[1] the writer offered for publication a systematic list of the introduced plants of the state, which grew without cultivation and had become more or less naturalized, with notes regarding their frequency, range within the state, and their native habitat. Special attention was called also to those introduced plants which were dangerous to agriculture, and whose eradication or control was advisable.

In the three years since the paper was prepared, much work has been done in securing additional data regarding our introduced flora, and at this time the following appended list, systematically arranged, numbering thirty-five species worthy of recognition, is offered.

The original list contained 263 numbers and those now offered increase the list to 298. The total number of Iowa Pteridophyta and Flowering Plants represented in the Herbarium at this date, September 15, 1933, is 1,613, of which the immigrant flora forms 18.4 per cent. This percentage will be greatly increased as time passes, through the destruction of many of our native plants, and the introduction of foreign species, many of them undesirable. In the appended list additional data are given, especially regarding those plants which threaten to become serious pests.

264. *Sorghum halepense* (L.) Pers. Johnson Grass. Frequent in cultivation and often escaped. It is a native of Asia.

265. *Phalaris canariensis* L. Bird-seed Grass. Frequent as an escape around dwellings; a native of Europe.

266. *Arrhenatherum elatius* (L.) Beauv. Oat-grass. Occasional in fields and waste places. Introduced from Europe.

267. *Hemerocallis fulva* L. Yellow Day Lily. Frequent as a garden escape. A native of Europe.

268. *Betula pendula* Roth. (*B. alba* L. in part). The common European White Birch in cultivation, but rare as an escape. This tree is especially liable to insect injury.

269. *Polygonum dumetorum* L. A European perennial. Rare unless overlooked on account of its close resemblance to one of our native species.

270. *Fagopyrum esculentum* Moench. Buckwheat. This common cultivar often persists for several years. Owing to our early frosts it is becoming less common in cultivation in this latitude.

271. *Amaranthus spinosus* L. The Thorny Amaranth. A rare introduction from Tropical America. It is common and very troublesome in our Southern States.

[1] Cratty, R. I. 1929. The immigrant flora of Iowa, Iowa State College Jour. Sci. 3: 247-269.

272. *Arenaria serpyllifolia* L. Rare in dry soil, Emmet Co. A native of
      Europe.
273. *Delphinium cultorum* Voss. The common Candle Larkspur of the
      gardens. It is very hardy and profuse bloomer and a frequent escape.
      It is of hybrid origin, a mingling of several Old World species.
274. *Berberis Thunbergii* DC. The Japanese Barberry, and a frequent
      escape. It is a valuable ornamental shrub, being immune to the grain
      rust which uses its near relative *B. vulgaris* as a winter host.
275. *Alyssum alyssoides* L. The common Sweet Alyssum which occasionally
      escapes to pastures and waste places. A native of Europe.
276. *Chorispora tenella* DC. This little crucifer from Asia has become
      established along a highway north-east of Sioux City.
277. *Erysimum parviflorum* Nutt. Western Wormseed. Infrequent; an
      introduction from the Western Plains.
278. *Radicula amphibia* (L.) Druce. An aquatic species, recently intro-
      duced from Europe to a river bank in Emmet Co.
279. *Reseda lutea* L. Sweet Mignonette. A garden cultivar from Europe,
      and an occasional escape.
280. *Geranium pusillum* Burm. fil. An occasional weed in lawns. A native
      of Europe.
281. *Oxalis corniculata* L. This is the species common around greenhouses.
      It is not the *O. corniculata* of our older manuals which is now *O.
      cymosa* Small.
282. *Ailanthus altissima* (Mill.) Swingle. The Chinese Tree-of-Heaven. It
      is quite common in cultivation and occurs as an escape from seed and
      also by suckering.
283. *Euphorbia Peplus* L. A rare introduction from Europe, and for-
      tunately not likely to prove troublesome.
284. *Falcaria vulgaris* Bernh. Sicklewort. A deep-rooted perennial from
      Europe. It spreads both by seeds and by running roots. It has been
      found well established in Sioux and Guthrie counties, and should be
      eradicated.
285. *Borago officinalis* L. Borage. This garden escape was collected in
      Benton County by the late Dr. L. H. Pammel. It is a native of
      Europe.
286. *Madia glomerata* Hook. Tarweed. This common native of the western
      plains has been collected as a waif in Mahaska and Emmet counties.
287. *Bidens bipinnata* L. This European Spanish Needle has made its ap-
      pearance in S.E. Iowa. It is very common in the Atlantic States.
288. *Anthemis tinctoria* L. The Yellow Ox-eye Camomile of Europe occurs
      as a garden escape in Clayton Co.
289. *Centaurea diffusa* Lam. This Bachelor's Button or Knap-weed is
      thoroughly established in Sioux Co. It is a native of S.E. Europe.
290. *Centaurea repens* L. Russian Knap-weed. This noxious introduction
      from S.E. Europe has made its appearance in Sioux Co. It is a hardy
      perennial and spreads by seed and by its extensive running roots. It
      should be added to our list of unlawful weeds.

291. *Sonchus uliginosus* Bieb. One of our Perennial Sow Thistles. This European plant is frequent in N.E. Iowa. It is a close relative, perhaps only a variety, of the unlawful species, *S. arvensis*.

292. *Crepis capillaris* (L.) Wallr. A harmless little plant introduced from Europe into waste places.

293. *Hieracium virosum* Pall. One of the European Hawkweeds. It has been collected in Floyd and Howard counties. This is its first recorded appearance in the United States.

294. *Hartmannia speciosa* (Nutt.) Small. (*Oenothera Nutt.*) White Primrose. Introduced on R.R. right-of-way, Kossuth Co. and probably elsewhere. A perennial plant worthy of cultivation.

295. *Anethum graveolens* L. Dill. An escape around gardens.

296. *Centaurea diffusa* Lam. One of the Star Thistles. Established in Sioux Co. (Dr. A. L. Bakke).

297. *Centaurea repens* L. Russian Knap-weed. A deep-rooted perennial, recently introduced in Sioux Co. (Dr. A. L. Bakke). It should be classed with our unlawful weeds.

298. *Hieracium virosum* Pallas. One of the Hawkweeds. Floyd Co. (Dr. Ada Hayden). Howard Co. (Kathryn Shields). The only known localities in America.

PHYLLOPHAGA OF IOWA[1]

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The genus Phyllophaga Harris (Gr. *phyllon* -leaf; *phagein*—to eat) includes a large group of beetles popularly known as ''June-bugs'' or ''May-beetles'' whose larvae are the common white grubs of the fields. From an economic point of view the depredations of both larvae and adults are well known. The adults frequently defoliate trees and shrubs by night and deposit their eggs in the soil by day, whereas the larvae or ''grubs'' are subterranean in habit and destroy the roots of numerous acres of farm, truck, and garden crops as well as great areas of grassland.

The contents of this paper are based upon data from 102,258 adult specimens taken in Iowa by various collectors during the past ten years. These specimens are represented by thirty-three species, one of which, *P. gracilis* (Burm.), is recorded in this state for the first time.

It has been impossible to compare specimens with the original types, so the synonymy given is that recorded in the literature. The species will be discussed in the order as given by Leng (1920) in his catalogue. The keys are adapted from Horn (1887), and since the females are so very similar the keys are of necessity arranged from the male characters.

DISTRIBUTION

The genus Phyllophaga is known to occur only in the Western Hemisphere from Hudson Bay to Argentine, including the West Indian Islands. From fifteen to twenty species may be found in most localities except along the Western Coast. Many species are known to have a rather wide distribution, whereas others have been taken only in limited areas. Junk (1912) listed 231 species for the world, many of which are synonyms or races; Leng (1920) catalogued 97 species from the United States and Canada; Leng and Mutchler (1927) reported 10 more species, and since that time 11 additional ones have been described from the United States and Canada, making a total of 118 species north of Mexico.

HISTORICAL REVIEW

Genus PHYLLOPHAGA Harris (1926)

Logotype—*hirticula* Knoch.

Melolontha Fabricius, 1775, Syst. Ent. :31.
Phyllophaga Harris, 1826, Mass. Agr. Jour. and Rpts., **10**:6. (Facsimile seen).
Stenothorax Harris, 1826, Mass. Agr. Jour. and Rpts., **10**:8. (Facsimile seen).
Rhizotrogus Berthold, 1827, Nat. Fam. d. Thierreichs: 362 (original not seen).
Lachnosterna Hope, 1837, Coleop. Man., pt. 1:99.
Holotricha Hope, 1837, Coleop. Man., pt. 1:99.
Ancylonycha Blanchard, 1845, Hist. Ins., 1:216.

Trichesthes Erichson, 1847, Nat. Ins. Deutschl., 3:658.   (Original not seen).
Trichestes Blanchard, 1850, Cat. Coll. Ent., 1:141.
Tostegoptera Blanchard, 1850, Cat. Coll. Ent., I:149.
Eugastra Le Conte, 1856, Acad. Phil., Jour., (2), 3:233.
Endrosa Le Conte 1856, Acad. Phil., Jour., (2), 3:234.
Gynnis Le Conte, 1856, Acad. Phil., Jour., (2), 3:262.

Harris (1826) separated the species of *Melolontha* into two genera; he retained *Melolontha* for those species with an antennal club of four segments, and proposed the name *Phyllophaga* for those species with an antennal club of three segments.   The generic name *Phyllophaga* was rejected by most early workers on the grounds that the original description failed to mark the limits of the genus.   Melsheimer (1853) accepted the latter name in his catalogue, but his paper does not seem to have been followed by later systematists.   The species now included in this genus have been placed in numerous genera by different authors, and European workers still recognize *Lachnosterna* Hope.   Glasglow (1912) revived the name *Phyllophaga* because the original publication was accompanied by the valid species *quercina, hirsuta, hirticula,* and *balia.*   He designated *P. hirticula* (Knoch) as the genotype (logotype).
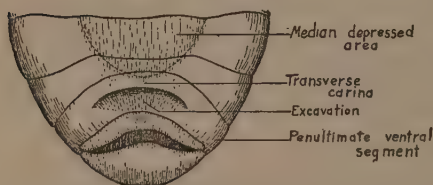
Fig. 1.   Ventral view of tip of male abdomen showing charactres.
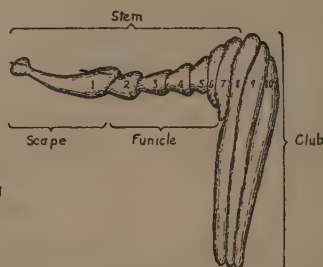
Fig. 2.   Antenna showing parts.

DESCRIPTION OF GENUS

Body oval, oblong, or cylindrical, yellowish brown to piceous.   Elytra without striae or grooves.   Six visible ventral segments rather firmly united, but with distinct sutures.   Mesosternum densely punctate, with more or less dense vestiture of hair.   Coxae transverse, not prominent.   Antennae lamellate with a three-jointed club.   Tarsal claws with a single tooth beneath near the middle.

BROODS

Life histories of June-beetles vary in length from one to four years, depending upon biotic conditions and the species concerned.   In general, however, it requires three years in Iowa to complete the development from egg to adult.   There are three broods, designated as broods A, B, and C, the adults of one brood appearing each year.   Four species, namely, *P. quercus, gracilis, ephilida,* and *spreta* have been reported in the literature as occurring in Iowa, but since the year in which the adults of these species were taken was not recorded, it is impossible to determine the brood to

which they should be referred. Records of the species for these three broods are shown in table 1. The data include the notes published by H. E. Jaques in 1926, 1927, and 1928; many records kindly sent to the writer by Dr. H. B. Hungerford and Prof. M. H. Swenk; unpublished notes of R. L. Webster, formerly of the Iowa Agricultural Experiment Station; many unpublished records of Dr. W. F. Wickham and Prof. H. E. Jaques; data from specimens in the collection of Iowa State College and several thousand collected by members of the department and the writer during the past three years.

TABLE 1. *Phyllophaga of Iowa*

Phyllophaga Species	Number of specimens of each species			
	Brood A	Brood B	Brood C	Total
P. hirticula (Knoch)	41,084	825	193	42,102
P. implicita (Horn)	9,980	14,662	1,609	17,208
P. fusca (Froel.)	937	38	5,531	15,549
P. tristis (Fab.)	10,647	75	10	10,732
P. futilis (Lec.)	2,062	3,440	1,914	7,416
P. rugosa (Mels.)	2,993	1,363	733	5,089
P. inversa (Horn)	507	316	83	906
P. crassissima (Blanch.)	157	111	381	649
P. hornii (Smith)	560	3		563
P. vehemens (Horn)	255		179	434
P. anxia (Lec.)	352	4	41	397
P. drakii (Kirby)	211	5	124	340
P. fraterna Harris	206	3	4	213
P. ilicis (Knoch)	140	5	4	149
P. micans (Knoch)	91	31	15	137
P. crenulata (Froel.)	53	13	36	102
P. marginalis (Lec.)	53			53
P. prunina (Lec.)	52	1		53
P. congrua (Lec.)	44			44
P. fervida (Fab.)	14		14	28
P. nitida (Lec.)	25	1		26
P. balia (Say)	23			23
P. bipartita (Horn)	14	1	2	17
P. fosteri (Burm.)	3	2	6	11
P. corrosa (Lec.)	8	1		9
P. vilifrons (Lec.)	4			4
P. barda (Horn)	2			2
P. lanceolata (Say)			1	1
P. longitarsa (Say)		1		1
P. gracilis (Burm.)				
P. quercus (Knoch)				
P. spreta (Horn)				
P. ephilida (Say)				
Total	70,477	20,901	10,880	102,258

KEY TO THE MALES OF GENUS PHYLLOPHAGA

1. Hind tibia with both spurs free... 2
   Hind tibia with one spur fixed.. 5

2. Body more or less pruinose...*quercus* ....p. 340
   Body with vestiture of scales or hair.. 3

3. Body with vestiture of scales...*lanceolata* ....p. 317
   Body with vestiture of hair.. 4

DESCRIPTION OF SPECIES

Phyllophaga lanceolata (Say)

(Plate I, fig. 1)

1824 *Melolontha lanceolata* Say, Acad. Phil., Jour., 3: 242, Le Conte ed. 2, 1869, p. 298.
1850 *Tostegoptera lanceolata* Blanchard, Cat. Coll. Ent., 1:149.
1855 *Tostegoptera lanceolata* Burmeister, Handb. Ent., 4, pt. 2: 356.
1856 *Ancylonycha lanceolata* Lacordaire, Gen. Coleop., 3: 285.
1856 *Lachnosterna lanceolata* Le Conte, Acad. Phil., Jour., (2), 3: 237.
1887 *Lachnosterna lanceolata* Horn, Am. Ent. Soc., Trans., 14: 216.
1887 *Lachnosterna lanceolata* Horn, Ent. Am., 3: 143.
1889 *Lachnosterna lanceolata* Smith, U. S. Nat. Mus., Proc., 11: 493.
1916 *Lachnosterna lanceolata* Davis, Jour. Econ. Ent., 9: 277.
1916 *Phyllophaga lanceolata* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1919 *Lachnosterna lanceolata* Hayes, Jour. Econ. Ent., 12: 109.
1928 *Phyllophaga lanceolata* Sim, N. J. Dept. Agr., Circ. 145: 9.

² Specimen not seen.

Body robust, subopaque, brownish to piceous, with vestiture of elongate, yellowish scales. Clypeus subconcave, rather broadly and vaguely emarginate, moderately reflexed; coarsely, deeply punctate; suture sinuate. Frons convex; punctures similar to those on clypeus. Antennae composed of ten segments. Pronotum subconvex, short and broad, widest in front of middle, sides angulate, crenate; punctures similar to those on frons, not so dense. Mesosternum with sparse vestiture of moderately long, scale-like hairs. Tooth of claw subbasal, small. Elytra granulate, rugulose, punctures similar to those on pronotum, much sparser; costae broad, feebly elevated, more or less glabrous.

Length, 13-17 mm.; width, 7-9 mm.

Male: Antennal club equal to stem. Abdomen with second, third, and fourth ventral segments with short, strongly elevated carina at middle; penultimate ventral segment with deep, transverse depression, apex abruptly and deeply emarginate; last ventral segment vaguely depressed, apex broadly and deeply emarginate. Hind tibia obliquely truncate; upper spur long, slender, slightly curved, acute; lower spur movable, slender, slightly curved, twisted at tip, acute, three-fourths length of upper.

Female: Antennal club shorter than funicle. Body ovate, wingless. Abdomen with second, third, and fourth ventral segments glabrous at middle, with piceous, roughened, elevated carinae; penultimate ventral segment vaguely concave; last ventral segment convex, apex broadly, not deeply emarginate.

Collected only at Ames and Sioux City. Food plants unknown.

Phyllophaga ephilida (Say)

(Plate I, fig. 3)

1825 *Melolontha ephilida* Say, Acad. Phil., Jour., 5: 196, in Le Conte ed. 2, 1869, p. 298.
1853 *Phyllophaga ephilida* Melsheimer, Cat. Coleop. U. S.: 59
1855 *Trichestes ephilida* Burmeister, Handb. Ent., 4: 359.
1855 *Trichestes ephilida* var. *longitarsis* Burmeister, Handb. Ent., 4: 359.   (not Say).
1856 *Lachnosterna ephilida* Le Conte, Acad. Phil., Jour., (2), 3: 241.
1856 *Lachnosterna burmeisteri* Le Conte, Acad. Phil., Jour., (2), 3: 144.
1887 *Lachnosterna ephilida* Horn, Am. Ent. Soc., Trans., 14: 225.
1887 *Lachnosterna ephilida* Horn, Ent. Am., 3: 144.
1889 *Lachnosterna ephilida* Smith, U. S. Nat. Mus., Proc., 11: 496.
1916 *Lachnosterna burmeisteri* Davis, Jour. Econ. Ent., 9: 273.
1916 *Phyllophaga ephilida* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1927 *Phyllophaga ephilida* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 13.
1928 *Phyllophaga ephilida* Sim, N. J. Dept. Agr., Circ. 145: 16.

Body elongate, moderately shiny, rufocastaneous, head and thorax darker. Clypeus concave, broadly, feebly emarginate, broadly reflexed; punctures moderately fine, dense, not deeply impressed; suture subangulate. Frons subconvex; punctures similar to those on clypeus. Antennae composed of ten segments. Pronotum short and convex, widest at middle, sides arcuate, entire; more coarsely, not so closely punctate as frons. Mesosternum with sparce vestiture of yellowish hair. Tooth of claw intramedian, strong. Elytra with punctures finer and denser than on pronotum; sutural costae strong, discal, and submarginal costae broad, feebly elevated.

Length, 14-19 mm.; width, 8-10 mm.

Male: Antennal club subequal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with roughened, semicircular de-

pression near apex, apex feebly emarginate; last ventral segment with rough, median depression, apex with moderately narrow and deep emargination. Hind tibia squarely truncate; upper spur long, lanceolate, subacute; lower spur fixed, obliquely truncate, obtuse, one-third length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with shallow, transverse depression near apex; last ventral segment convex, apex entire.

Jaques (1926) reported this insect as occurring in Iowa.

Phyllophaga longitarsa (Say)

(Plate I, fig. 2)

1824 *Melolontha longitarsa* Say, Acad. Phil., Jour., 3: 241, in Le Conte ed. 2, 1889, p. 141.
1853 *Phyllophaga longitarsa* Melsheimer, Cat. Coleop. U. S.: 59.
1855 *Trichestes longitarsis* Burmeister, Handb. Ent., 4, pt. 2: 359.
1856 *Lachnosterna longitarsis* Le Conte, Acad. Phil., Jour., (2), 3: 240.
1856 *Lachnosterna longitarsis* var. *frontalis* Le Conte, Acad. Phil., Jour., (2), 3: 239.
1887 *Lachnosterna longitarsus* Horn, Am. Ent. Soc., Trans., 14: 226.
1889 *Lachnosterna longitarsis* Smith, U. S. Nat. Mus., Proc., 11: 496.
1916 *Phyllophaga longitarsa* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916 *Phyllophaga longitarsa* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 234.
1925 *Phyllophaga longitarsa* Hayes, Kans. Agr. Expt. Sta., Tech. Bul. 16: 23-28.
1927 *Phyllophaga longitarsa* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 17.
1928 *Phyllophaga longitarsa* Sim, N. J. Dept. Agr., Circ.. 145: 11.

Body slender, elongate, moderately shiny, pale yellow, head fuscous to piceous. Clypeus concave, abruptly and deeply emarginate, broadly reflexed; smooth, to coarsely and feebly punctate; suture angulate. Frons convex; coarsely, densely, rather deeply punctate. Antennae composed of nine segments. Pronotum convex, widest at middle, sides subangulate, entire; punctures coarser, sparser, and more feebly impressed than on frons. Mesosternum with sparse vestiture of long yellowish hair. Tooth of claw different in male and female. Elytra rugulose, punctures much finer and denser than on pronotum; sutural costae strong, discal and submarginal costae indistinct.

Length, 10-13 mm.; width, 5-7 mm.

Male: Antennal club subequal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with narrow, longitudinal, median depression; last ventral segment concave, apex broadly, feebly emarginate. Hind tibia obliquely truncate; upper spur lanceolate, curved, acute; lower spur fixed, slender, lanceolate, acute, one-third length of upper. Tooth of claw near base.

Female: Antennal club slightly shorter than funicle. Penultimate ventral segment with transverse, lateral depression; last ventral segment convex, apex entire. Tooth of claw nearly median.

A small light brown species, collected at Columbus Junction, Ames, Iowa City and Sioux City. Nothing is known regarding its feeding habits.

Phyllophaga gracilis (Burmeister)

(Plate I, fig. 5)

1855 *Trichestes gracilis* Burmeister, Handb. Ent., 4: 361.
1856 *Endrosa volvula* Le Conte, Acad. Phil., Jour., (2), 3: 335.

1856 *Lachnosterna inana* Le Conte, Acad. Phil., Jour., (2), **3**: 242.
1887 *Lachnosterna inana* Horn, Am. Ent. Soc., Trans., **14**: 242.
1887 *Lachnosterna inana* Horn, Ent. Am., **3**: 144.
1887 *Endrosa volvula* Horn, Am. Ent. Soc., Trans., **14**: 235.
1887 *Lachnosterna gracilis* Horn, Am. Ent. Soc., Trans., **14**: 230.
1887 *Lachnosterna gracilis* Horn, Ent. Am., **3**: 143.
1889 *Lachnosterna gracilis* Smith, U. S. Nat. Mus., Proc., **11**: 497.
1916 *Phyllophaga gracilis* Glasglow, Ill. Nat. Hist., Bul. **11**: 372.
1927 *Phyllophaga gracilis* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 23.
1928 *Phyllophaga gracilis* Sim, N. J. Dept. Agr., Circ. 145: 13.
1928 *Phyllophaga gracilis* Luginbill, Ann. Ent. Soc. Am., **21**: 84.

Body elongate, moderately shiny, pale brown, head and thorax darker. Clypeus concave, rather deeply and abruptly emarginate, broadly reflexed; punctures moderately coarse, not deeply impressed; suture angulate. Frons broad, flat; punctures similar to those on clypeus, not so dense. Antennae normally composed of ten segments. Pronotum convex, widest in front of middle, sides arcuate, vaguely crenate; punctures similar to those on frons, not so dense. Mesosternum with sparse vestiture of short, inconspicuous, yellowish hairs. Tooth of claw intramedian, small. Elytra with punctures similar to those on pronotum, denser; sutural costae strong, discal and submarginal costae indistinct.

Length, 10-13 mm.; width, 5-6 mm.

Male: Antennal club equal to stem. Abdomen flattened at middle; penultimate ventral segment with narrow, arcuate ridge; last ventral segment feebly depressed at middle, apex with shallow, rather broad emargination. Hind tibia excavated at base of lower spur; upper spur long, lanceolate, curved, subacute; lower spur fixed, linear, decurved, subacute, equal to upper.

Female: Antennal club equal to funicle. Penultimate ventral segment slightly depressed at sides; last ventral segment narrow, apex entire.

One female specimen bearing the label "Iowa" is in the collection of Iowa State College.

Phyllophaga futilis (Le Conte)

(Plate I, fig. 4)

1850 *Lachnosterna futilis* Le Conte, Agassiz, Lake Superior: 226.
1853 *Phyllophaga futilis* Melsheimer, Cat. Coleop. U. S.: 59.
1855 *Ancylonycha gibbosa* Burmeister, Handb. Ent., **4**: 324.
1856 *Lachnosterna decidua* Le Conte, Acad. Phil., Jour., (2), **3**: 246.
1856 *Lachnosterna serricornis* Le Conte, Acad. Phil., Jour., (2), **3**: 247.
1856 *Lachnosterna futilis* Le Conte, Acad. Phil., Jour., (2), **3**: 243.
1873 *Lachnosterna futilis* Le Conte, Acad. Phil., Proc., 330.
1887 *Lachnosterna futilis* Horn, Ent. Am., **3**: 144.
1887 *Lachnosterna serricornis* Horn, Ent. Am., **3**: 144.
1887 *Lachnosterna gibbosa* Horn, Am. Ent. Soc., Trans., **14**: 230.
1887 *Lachnosterna gibbosa* Horn, Ent. Am., **3**: 143.
1916 *Lachnosterna gibbosa* Davis, Jour. Econ. Ent., **9**: 275.
1916 *Phyllophaga futilis* Glasglow, Ill. Nat. Hist., Bul. **11**: 371.
1916 *Phyllophaga futilis* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 225.
1927 *Phyllophaga futilis* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 25.
1928 *Phyllophaga futilis* Sim, N. J. Dept. Agr., Circ. 145: 43.

Body ovate, moderately shiny, rufotestaceous, head darker. Clypeus flat, feebly and abruptly emarginate, moderately reflexed; closely, rather coarsely punctate; suture sinuate. Frons convex; punctured similar to

clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest in front of middle, sides arcuate, entire or vaguely irregular; punctures similar to those on frons, much sparser. Tooth of claw median, long. Elytra rugulose, punctures similar to those on pronotum, more closely placed; sutural costae strong, narrow, discal costae wide, elevated, submarginal costae indistinct.

Length, 12-17 mm.; width, 7-9 mm.

Male: Antennal club subequal to stem. Abdomen with moderately broad, median, longitudinal depression; penultimate ventral segment with arcuate roughened ridge; last ventral segment with deep cupuliform concavity, with elevation overhanging at apex. Hind tibia excavated; upper spur broad, lanceolate, obtuse; lower spur fixed, lower half strongly arcuate, apical half straight, subequal to upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with transverse depression; last ventral segment convex, apex excavated on either side of middle, leaving median triangular tooth.

Many specimens from Ames, Des Moines, Central City, Leon, Clermont, Muscatine, Hampton, Mt. Pleasant, Amana, Bloomfield, Pleasant Valley, Dubuque, Dyersville, Davenport, Atlantic, Farmersburg, Marshalltown, Waverly, Missouri Valley, Onawa, Chariton, Grinnell, Sioux City, Oakland, Creston, Keokuk, Morning Sun, Mt. Union, Iowa City, Kossuth County, Appanoose County, Lee County, Cerro Gordo County, Clayton County, Fremont County, Sioux County, Monroe County, Floyd County, Des Moines County, Wapello County, Page County, and Lyon County. Collected feeding on bur oak, elm, butternut, hawthorne, gooseberry, hazel, cherry, plum, privet, Cornus, Caragana, apple, linden, birch, buckeye, and wild plum.

Phyllophaga congrua (Le Conte)

(Plate II, fig. 6)

1850 *Ancylonycha fervens* Blanchard, Cat. Coll. Ent., **1**: 133 (preoccupied).
1856 *Lachnosterna congrua* Le Conte, Acad. Phil., Jour., (2), **3**: 243.
1873 *Ancylonycha congrua* Le Conte, Acad. Phil., Proc., 330.
1887 *Lachnosterna congrua* Horn, Am. Ent. Soc., Trans., 14: 232.
1887 *Lachnosterna congrua* Horn, Ent. Am. **3**: 144.
1889 *Lachnosterna congrua* Smith, U. S. Nat. Mus., Proc., **11**: 498.
1916 *Lachnosterna congrua* Davis, Jour. Econ. Ent., **9**: 273.
1916 *Phyllophaga congrua* Glasglow, Ill. Nat. Hist., Bul. 11: 372.
1916 *Phyllophaga congrua* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 233.
1927 *Phyllophaga congrua* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15. 27.
1928 *Phyllophaga congrua* Sim, N. J. Dept. Agr., Circ. 145: 37.

Body rather robust, moderately shiny, castenous to piceous. Clypeus concave, with moderately broad, shallow emargination, broadly reflexed; punctures coarse and dense, not deeply impressed; suture sinuate. Frons convex; more closely and coarsely punctate than clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at base, sides sinuous, margin entire; punctures similar to those on frons, not so dense or so deeply impressed. Tooth of claw moderately strong, median. Elytra rugulose, punctures similar to those on pronotum; sutural costae broad, strong, discal costae vague, submarginal costae narrow.

Length, 15-19 mm.; width, 8-11 mm.

Male: Antennal club subequal to stem. Abdomen with moderately broad, median depression; penultimate ventral segment acutely notched at middle by longitudinal, median depression, with roughened, semicircular

area near apex; last ventral segment with deep, triangular depression, apex sinuous, bilobed at middle. Hind tibia with deep excavation at base of fixed spur; upper spur slender, lanceolate, slightly decurved, acute; lower spur fixed, linear-lanceolate, slightly twisted and decurved, acute, three-fourths length of upper.

Female: Antennal club shorter than funicle. Abdomen with vague, longitudinal depression; penultimate ventral segment feebly depressed laterally; last ventral segment broadly, and shallowly emarginate.

Known only from Missouri Valley and Onawa. Found feeding on the leaves of ash and walnut.

Phyllophaga prunina (Le Conte)

(Plate II, fig. 7)

1846 *Ancylonycha pruinosa* Melsheimer, Acad. Phil., Proc., **2**: 139 (preoccupied).
1850 *Ancylonycha pruinosa* Blanchard, Cat. Coll. Ent., **1**: 133.
1853 *Phyllophaga pruinosa* Melsheimer, Cat. Coleop. U. S., 59.
1855 *Ancylonycha fraterna* Burmeister, Handb. Ent., **4**, pt. 2: 322 (not Harris).
1856 *Lachnosterna prunina* Le Conte, Acad. Phil., Jour. (2), **3**: 251.
1887 *Lachnosterna prunina* Horn, Am. Ent. Soc., Trans., **14**: 234.
1887 *Lachnosterna prunina* Horn, Ent. Am., **3**: 144.
1889 *Lachnosterna prunina* Smith, U. S. Nat. Mus., Proc., **11**: 498.
1916 *Phyllophaga prunina* Glasglow, Ill. Nat. Hist., Bul. **11**: 371.
1916 *Phyllophaga prunina* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 234.
1927 *Phyllophaga prunina* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 29.

Body ovate, elytra pruinose, head, pronotum, scutellum, and pygidium shiny, castaneous to piceous. Clypeus flat, rather abruptly and deeply emarginate, narrowly reflexed; coarsely, moderately deeply punctate; suture angulate. Frons convex; coarser and more deeply punctate than clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides subangulate, serrate; punctures variolate, not so dense as on frons. Tooth of claw median, strong. Elytra rugulose, finely and moderately closely punctate; costae distinct, broad, feebly elevated.

Length, 17-18 mm.; width, 9-11 mm.

Male: Antennal club subequal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with strongly elevated, roughened, transverse ridge; last ventral segment concave, elevated at base, apex broadly, rather deeply emarginate. Hind tarsa deeply excavated at base of lower spur; upper spur slender, lanceolate, subacute; lower spur cylindrical, subacute, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment feebly, transversely depressed; last ventral segment deeply depressed at middle, apex broadly and deeply emarginate.

Specimens have been taken at Leon, Ames, Dyersville, Manchester, Mt. Pleasant, and Keosauqua. Collected on the leaves of white oak, hazel and hawthorne.

Phyllophaga crassissima (Blanchard)

(Plate II, fig. 8)

1850 *Ancylonycha crassissima* Blanchard, Cat. Coll. Ent., **1**: 133.
1850 *Ancylonycha fervida* Blanchard, Cat. Coll. Ent., **1**: 133 (not Fab.).
1853 *Phyllophaga crassissima* Melsheimer, Cat. Coleop. U. S.: 59.
1856 *Lachnosterna obesa* Le Conte, Acad. Phil., Jour., (2), **3**: 251.

1856 *Lachnosterna robusta* Le Conte, Acad. Phil., Jour., (2), **3**: 257.
1873 *Lachnosterna obesa* Le Conte, Acad. Phil., Proc.: 330.
1875 *Lachnosterna robusta* Horn, Am. Ent. Soc., Trans., **5**: 143.
1887 *Lachnosterna obesa* Horn, Ent. Am., **3**: 144.
1887 *Lachnosterna robusta* Horn, Ent. Am., **3**: 145.
1887 *Lachnosterna generosa* Horn, Am. Ent. Soc., Trans., **14**: 222.
1887 *Lachnosterna crassissima* Horn, Am. Ent. Soc., Trans., **14**: 239.
1889 *Lachnosterna crassissima* Smith, U. S. Nat. Mus., Proc., **11**: 499.
1916 *Lachnosterna crassissima* Davis, Jour. Econ. Ent., **9**: 273.
1916 *Phyllophaga crassissima* Glasglow, Ill. Nat. Hist., Bul. **11**: 372.
1916 *Phyllophaga crassissima* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 233.
1922 *Lachnosterna crassissima* Hayes, Am. Micr. Soc., Trans., **41**: 1-29.

Body ovate, robust, feebly iridescent, pruinose, rufocastaneous. Clypeus concave, rather abruptly and shallowly emarginate, broadly reflexed; punctures moderately coarse, closely placed, not deeply impressed; suture subangulate. Frons subconvex; punctures coarser and less deeply impressed than on clypeus. Antennae composed of ten segments. Pronotum short, broad, convex, widest in front of middle, sides arcuate, crenate; punctures similar to those on frons, evenly placed, but not so deeply impressed. Tooth of claw strong, different in male and female. Elytra slightly rugulose, less densely punctate than pronotum; sutural costae strong, discal and submarginal costae indistinct.

Length, 15-21 mm.; width, 9-12 mm.

Male: Antennal club longer than stem. Abdomen flattened at middle; penultimate ventral segment with feeble, roughened, transverse ridge; last ventral segment with smooth, median depression, rather broadly, moderately deeply emarginate. Hind tibia squarely truncate; upper spur slender, slightly curved, acute; lower spur fixed, sublinear, obtuse, about one-half length of upper. Tarsal claw with tooth intramedian.

Female: Antennal club subequal to funicle. Penultimate ventral segment with vague, median, longitudinal depression; last ventral segment slightly flattened, with moderately wide, deep depression. Tarsal claw with tooth median.

Taken only at lights; Pleasant Valley, Bloomfield, Sioux City, Davenport, Keosauqua and Muscatine.

Phyllophaga inversa (Horn)

(Plate II, fig. 9)

1887 *Lachnosterna inversa* Horn, Am. Ent. Soc., Trans., **14**: 241.
1889 *Lachnosterna inversa* Smith, U. S. Nat. Mus., Proc., **11**: 500.
1916 *Lachnosterna inversa* Davis, Jour. Econ. Ent., **9**: 276.
1916 *Phyllophaga inversa* Glasglow, Ill. Nat. Hist., Bul. 11. 373.
1916 *Phyllophaga inversa* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 224.
1928 *Phyllophaga inversa* Sim, N. J. Dept. Agr., Circ. 145: 36.

Body ovate, moderately shiny, rufocastaneous to dark brown. Clypeus subconcave, rather abruptly and shallowly emarginate, broadly reflexed; punctures moderately coarse, not deeply impressed; suture sinuate. Frons convex; more coarsely and closely punctate than clypeus. Antennae composed of ten segments. Pronotum irregularly convex, short and broad, widest at middle, sides angulate, vaguely crenate; coarser, more sparsely, and not so deeply punctate as frons. Tooth of claw median, moderately large. Elytra rugulose, punctures indistinct, finer, more closely placed

and not so deeply impressed as on pronotum; sutural costae broad, strong, discal and submarginal costae broad, moderately elevated.

Length, 15-18 mm.; width, 8-11 mm.

Male: Antennal club subequal to stem. Abdomen with broad, median depression; penultimate ventral segment with median, semicircular, roughened depression; last ventral segment with broad, transverse depression, apex slightly sinuous. Hind tibia obliquely truncate; upper spur slender, lanceolate, twisted at apex, acute; lower spur fixed, broad, curved, obtuse, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with transverse depression; last ventral segment convex, apex broadly and feebly emarginate.

Recorded from Leon, Ames, Dubuque, Dyersville, Iowa City, Chariton, Davis County, and Appanoose County. The known host plants are white oak, hickory, willow, hazel, hawthorne, cherry, Caragana, plum, and walnut.

Phyllophaga bipartita (Horn)

(Plate III, fig. 10)

1887 *Lachnosterna bipartita* Horn, Am. Ent. Soc., Trans., **14**: 242.
1889 *Lachnosterna bipartita* Smith, U. S. Nat. Mus., Proc., **11**: 500.
1916 *Lachnosterna bipartita* Davis, Jour. Econ. Ent., **9**: 272.
1916 *Phyllophaga bipartita* Glasglow, Ill. Nat. Hist., Bul. 11: 373.
1916 *Phyllophaga bipartita* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 228.
1925 *Phyllophaga bipartita* Hayes, Kans. Agr. Expt. Sta., Tech. Bul. 16: 28.
1927 *Phyllophaga bipartita* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 34.
1928 *Phyllophaga bipartita* Sim, N. J. Dept. Agr., Circ. 145: 29.

Body oblong, moderately shiny, castaneous to piceous. Clypeus subconcave, broadly, not deeply emarginate, moderately reflexed; coarsely, rather deeply punctate; suture sinuate. Frons with punctures similar to those on clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides arcuate, crenate; punctured similar to frons. Tooth of claw long, median. Elytra somewhat rugulose, punctures similar to those on pronotum, less deeply impressed; sutural costae strong, first discal costae broad, distinct, submarginal costae indistinct in posthumeral region.

Length, 15-19 mm.; width, 8-10 mm.

Male: Antennal club equal to stem. Abdomen with moderately broad, longitudinal depression; penultimate ventral segment with roughened, transverse carina, narrowly divided at middle; last ventral segment concave, with vague longitudinal depression, apex acutely emarginate. Hind tibia obliquely truncate; upper spur flattened, slightly curved, lanceolate, subacute; lower spur fixed, broad, lanceolate, curved, acute, two-thirds length of upper.

Female: Antennal club slightly shorter than funicle. Penultimate ventral segment with feeble, transverse depression extending obliquely foreward; last ventral segment excavated on each side of middle, leaving broad, triangular, median tooth at apex.

Taken at McGregor, Dyersville, Keokuk, and Keosauqua on white oak, the only known food plant in the state.

Phyllophaga micans (Knoch)

(Plate III, fig. 11)

1801 *Melolontha micans* Knoch, Neue Beytr. Ins., **1**: 77.
1817 *Melolontha micans* Schönherr, Syn. Ins., **1**: 171.
1850 *Ancylonycha micans* Blanchard, Cat. Coll. Ent., **1**: 138.
1855 *Ancylonycha micans* Burmeister, Handb. Ent., **4**, pt. **2**: 323.
1856 *Lachnosterna sororia* Le Conte, Acad. Phil., Jour., (2), **3**: 246.
1856 *Lachnosterna micans* Le Conte, Acad. Phil., Jour., (2), **3**: 247.
1887 *Lachnosterna micans* Horn, Am. Ent. Soc., Trans., **14**: 242.
1887 *Lachnosterna micans* Horn, Ent. Am., **3**: 142.
1889 *Lachnosterna micans* Smith, U. S. Nat. Mus., Proc., **11**: 500.
1916 *Phyllophaga micans* Glasglow, Ill. Nat. Hist., Bul. **11**: 371.
1916 *Phyllophaga micans* Forbes, Ill. Agr. Expt. Sta., Bul. **186**: 227.
1927 *Phyllophaga micans* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 35.
1928 *Phyllophaga micans* Luginbill, Ann, Ent. Soc. Am., **21**: 76.

Body elongate, pruinose, brownish-black. Clypeus concave, feebly and broadly emarginate, moderately reflexed; punctures moderately coarse and deeply impressed; suture sinuous. Frons convex; slightly more coarsely and sparsely punctate than clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides arcuate, entire, much coarser and more sparsely punctate than frons. Tooth of claw median, strong. Elytra with punctures like pronotum but finer; sutural costae broad, not strongly elevated, discal and submarginal costae broad, indistinct.

Length, 15-17 mm.; width, 8-9 mm.

Male: Antennal club shorter than stem. Abdomen broadly flattened at middle; penultimate ventral segment with feebly elevated, roughened, arcuate ridge; last ventral segment deeply depressed at middle, apex broadly, rather deeply emarginate. Hind tibia obliquely truncate; upper spur lanceolate, curved, subacute; lower spur fixed, broad, squarely truncate, one-half length of upper.

Female: Antennal club shorter than funicle. Abdomen with vague longitudinal depression; penultimate ventral segment feebly and transversely depressed; last ventral segment strongly elevated at base, feebly flattened at middle, apex rather deeply and broadly emarginate.

Collections have been made at Leon, Iowa City, Mt. Pleasant, and Keosauqua. Found feeding on hickory and shingle oak.

Phyllophaga vehemens (Horn)

(Plate III, fig. 12)

1887 *Lachnosterna vehemens* Horn, Am. Ent. Soc., Trans., **14**: 244.
1889 *Lachnosterna vehemens* Smith, U. S. Nat. Mus., Proc., **11**: 501.
1916 *Lachnosterna vehemens* Davis, Jour. Econ. Ent., **9**: 277-278.
1916 *Phyllophaga vehemens* Glasglow, Ill. Nat. Hist., Bul. **11**, 373.
1916 *Phyllophaga vehemens* Forbes, Ill. Agr. Expt. Sta., Bul. **186**: 231.
1925 *Phyllophaga vehemens* Hayes, Kans. Agr. Expt. Sta., Tech. Bul. **16**: 35-41.
1927 *Phyllophaga vehemens* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 38.
1928 *Phyllophaga vehemens* Sim, N. J. Dept. Agr., Circ. **145**: 28.
1928 *Phyllophaga vehemens* Luginbill, Ann. Ent. Soc. Am. **21**: 67.

Body ovate, widened posteriorly, shiny, dark brown to piceous. Clypeus subconcave, rather broadly, not deeply emarginate; punctures moderately coarse, not deeply impressed; suture angulate. Frons convex; punctures similar to those on clypeus, more deeply impressed and less dense near suture. Antennae composed of ten segments. Pronotum convex, widest

in front of middle, sides arcuate, vaguely crenate: punctures finer, not so deeply impressed as on frons. Tooth of claw median, strong. Elytra rugulose, punctures similar to those on pronotum, finer; sutural costae broad, distinct, discal and submarginal costae broad, feebly elevated.

Length, 21-23 mm.; width, 11-13 mm.

Male: Antennal club shorter than stem. Abdomen broadly flattened at middle; penultimate ventral segment with strong, sinuate, roughened ridge; last ventral segment with cupuliform depression, apex broadly, not deeply emarginate. Hind tibia squarely truncate; upper spur long, linear, obtuse; lower spur fixed, linear, hooked at tip, three-fourths as long as upper. Metathoracic femur broadly angulate.

Female: Antennal club shorter than funicle. Penultimate ventral segment with transverse depression; last ventral segment convex, apex broadly, not deeply emarginate.

This species has been collected at Onawa, Missouri Valley, Sioux City, Oskaloosa, Wapello County, Van Buren County, and Iowa County. Taken on ash and walnut.

Phyllophaga fusca (Froelich)

(Plate III, fig. 13)

1789 *Melolontha fervida* Oliver, Entom., 1: 24 (preoccupied).
1792 *Melolontha fusca* Froelich, Natur., Stueck., **26**: 99.
1817 *Melolontha fervens* Gyllenhall, Syn. Ins., 1, pt. 3: 74.
1837 *Rhizotrogus fervens* Kirby, Faun. Bor.-Am., 4: 132.
1850 *Ancylonycha fusca* Blanchard, Cat. Coll. Ent., **1**: 133.
1856 *Lachnosterna fusca* Le Conte, Acad. Phil., Jour., (2), **3**: 244.
1884 *Lachnosterna fusca* Casey, N. Am. Coleop., pt. 1: 39.
1887 *Lachnosterna fusca* Horn, Am. Ent. Soc., Trans., **14**: 245.
1887 *Lachnosterna fusca* Horn, Ent. Am., **3**: 144.
1889 *Lachnosterna fusca* Smith, U. S. Nat. Mus., Proc., **11**: 505.
1916 *Lachnosterna fusca* Davis, Jour. Econ. Ent., **9**: 274.
1916 *Phyllophaga fusca* Glasglow, Ill. Nat. Hist., Bul. 11: 373.
1916 *Phyllophaga fusca* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 223.
1925 *Phyllophaga fusca* Hayes, Kans. Agr. Expt. Sta.. Tech. Bul. 16: 41-45.
1928 *Phyllophaga fusca* Sim, N. J. Dept. Agr., Circ. 145: 24.
1928 *Phyllophaga fusca* Luginbill, Ann. Ent. Soc. Am., 21: 66.

Body oblong, shiny, light brown to piceous. Clypeus concave, broadly and feebly emarginate, broadly reflexed; punctures moderately fine, not deeply impressed; suture subangulate. Frons convex; punctures similar to those on clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides arcuate, indented where hairs arise from margin; punctures similar to those on frons, more sparse. Tooth of claw median, strong. Elytra vaguely rugulose; punctures denser, not so coarse as on pronotum; sutural costae strong, first discal costae wide, feebly elevated, submarginal costae narrow, distinct.

Length, 17-23 mm.; width, 10-12 mm.

Male: Antennal club subequal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with transverse ridge, roughened at middle, overhanging at ends; last ventral segment with roughened, median depression, apex entire. Hind tibia obliquely truncate; upper spur long, slender, acuminate; lower spur fixed, slightly curved, obliquely truncate, two-thirds length of upper.

Female: Antennal club shorter than funicle. Abdomen with vague, median depression; penultimate ventral segment with transverse depression

extending obliquely forward to base; last ventral segment convex, apex rather broadly and feebly emarginate.

Common, known from Central City, Ames, Des Moines, Leon, Sioux City, Hampton, Marquette, Amana, Bloomfield, Dubuque, Dyersville, Davenport, Edgewood, Manchester, Keokuk, Farmersburg, Waukon, Oneida, Arlington, Iowa City, Mt. Pleasant, Stockport, Chariton, Muscatine, Grinnell, Clermont, Oakland, New Hampton, Mt. Union, Boone County, Taylor County, Allamakee County, Iowa County, Des Moines County, Powesheik County, Van Buren County, Louisa County and Hamilton County. The host plants include bur oak, hickory, elm, willow, butternut, shingle oak, red oak, white oak, walnut, silver poplar, large-toothed aspen, gooseberry, hazel, poplar, privet, plum, box elder, birch, Caragana, linden, cherry, hawthorne, quaking aspen, Cornus and wild plum.

Phyllophaga hornii (Smith)

(Plate IV, fig. 14)

1889   *Lachnosterna hornii* Smith, Ent. Am., **5**: 95.
1889   *Lachnosterna hornii* Smith, U. S. Nat. Mus., Proc., **11**: 510.
1912   *Lachnosterna horni* Junk, Cat. Coleop., pt. 49: 192.
1916   *Phyllophaga hornii* Glasglow, Ill. Nat. Hist., Bul. **11**: 373.
1916   *Phyllophaga hornii* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 234.
1927   *Phyllophaga hornii* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 40.
1928   *Phyllophaga hornii* Sim, N. J. Dept. Agr., Circ. 145: 21.

Body oblong, moderately shiny, deep brown to piceous. Clypeus flat, moderately broad, not deeply emarginate, narrowly reflexed; punctures coarse, dense, rather deeply impressed; suture sinuate. Frons subconvex; punctures similar to those on clypeus, but less dense. Antennae composed of ten segments. Pronotum convex, widest back of middle, sides broadly angulate, feebly crenate; punctures much coarser, not so dense as on frons. Tooth of claw median, long. Elytra rugulose, with punctures as dense as on pronotum, much finer, not so deeply impressed; sutural, discal, and submarginal costae wide, moderately strong.

Length, 19-21 mm.; width, 10-12 mm.

Male: Antennal club slightly longer than funicle. Abdomen broadly flattened at middle; penultimate ventral segment with strong arcuate ridge broadly divided, smooth at middle; last ventral segment deeply, rather broadly depressed at middle, apex deeply and abruptly emarginate. Hind tibia squarely truncate; upper spur flattened, curved, subacute; lower spur lanceolate, obtuse, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with strong, transverse depression near apex; last ventral segment with shallow, transverse depression near apex, apex sinuate.

A large dark species, taken at Leon, Mt. Pleasant, Mahaska County, and Davis County on hickory and shingle oak.

Phyllophaga fervida (Fabricius)

(Plate IV, fig. 15)

1775   *Melolontha fervida* Fabricius, Species Ins.: 32.
1801   *Melolontha quercina* Knoch, Neue Beytr. Ins., **1**: 74.
1826   *Phyllophaga quercina* Harris, Mass. Agr. Jour. and Rpts., **10**: 1-12.
1853   *Phyllophaga fervida* Melsheimer, Cat. Coleop. U. S.: 59.
1855   *Ancylonycha quercina* Burmeister, Handb. Ent., **4**, pt. 2: 319.

1888   *Lachnosterna arcuata* Smith, Ins. Life, 1: 183.
1889   *Lachnosterna arcuata* Smith, U. S. Nat. Mus., Proc., 11: 503.
1889   *Lachnosterna fervida* Chittenden, U. S. Dept. Agr., Bur. Ent. Bul. 19: 1-77.
1916   *Phyllophaga fervida* Glasglow, Ill. Nat. Hist., Bul. 11: 370.
1916   *Phyllophaga fervida* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 230.
1927   *Phyllophaga fervida* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 42.
1928   *Phyllophaga fervida* Sim, N. J. Dept. Agr., Circ. 145: 28.
1928   *Phyllophaga fervida* Luginbill, Ann. Ent. Soc. Am., 21: 65.

Body ovate, shiny, brown to piceous. Clypeus flat, abruptly, not deeply emarginate, narrowly reflexed; punctures moderately fine, not deeply impressed; suture sinuate. Frons convex; punctures similar to those on clypeus, less dense. Antennae composed of ten segments. Pronotum convex, widest at middle, sides broadly arcuate, irregular; punctures similar to those on frons. Tooth of claw median, strong. Elytra rugulose, punctures finer and denser than on pronotum; sutural costae broad, strong, discal and submarginal costae moderately broad, indistinct.

Length, 18-21 mm.; width, 10-11 mm.

Male: Antennal club slightly longer than stem. Abdomen broadly flattened at middle; penultimate ventral segment with transverse, arcuate, overhanging ridge reaching hind margin of segment; last ventral segment flattened, apex broadly, moderately deeply emarginate. Hind tibia obliquely truncate; upper spur lanceolate, obtuse; lower spur lanceolate, subacute, two-thirds length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment transversely depressed; last ventral segment convex, apex broadly and deeply emarginate.

Collected in Hamilton and Van Buren Counties. Food plants unknown.

Phyllophaga anxia (Le Conte)

(Plate IV, fig. 16)

1850   *Lachnosterna anxia* Le Conte, Agassiz, Lake Superior: 226.
1850   *Ancylonycha brevicollis* Blanchard, Cat. Coll. Ent., 1: 132.
1850   *Ancylonycha puncticollis* Blanchard, Cat. Coll. Ent. 1: 133.
1853   *Phyllophaga anxia* Melsheimer, Cat. Coleop. U. S.: 59.
1855   *Ancylonycha puncticollis* Burmeister, Handb. Ent., 4, pt. 2: 319.
1855   *Ancylonycha brevicollis* Burmeister, Handb. Ent., 4, pt. 2: 322.
1856   *Lachnosterna anxia* Le Conte, Acad. Phil., Jour., (2), 3: 245.
1856   *Lachnosterna brevicollis* Le Conte, Acad. Phil., Jour., (2), 3: 245.
1856   *Lachnosterna puncticollis* Le Conte, Acad. Phil., Jour., (2), 3: 245.
1856   *Lachnosterna cephalica* Le Conte, Acad. Phil., Jour., (2), 3: 256.
1866   *Ancylonycha uninotata* Walker, Natur. in Vanc. Isl., B. C., 2: 323.
1873   *Lachnosterna puncticollis* Le Conte, Acad. Phil., Proc.: 330.
1873   *Lachnosterna brevicollis* Le Conte, Acad. Phil., Proc.: 350.
1884   *Lachnosterna anxia* Casey, N. Am. Coleop., pt. 1: 29.
1887   *Lachnosterna cephalica* Horn, Ent. Am., 3: 144.
1888   *Lachnosterna dubia* Smith, Ins. Life, 1: 183.
1889   *Lachnosterna dubia* Smith, U. S. Nat. Mus., Proc., 11: 504.
1889   *Lachnosterna inseparata* Smith, Ent. Am., 5: 93.
1897   *Lachnosterna alpina* Linell, U. S. Nat. Mus., Proc., 18: 726.
1916   *Phyllophaga anxia* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916   *Phyllophaga anxia* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 227.
1927   *Phyllophaga anxia* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 47.
1928   *Phyllophaga anxia* Luginbill, Ann. Ent. Soc. Am., 21: 71.
1928   *Phyllophaga anxia* Sim, N. J. Dept. Agr., Circ. 145: 29

Body oblong, shiny, light brown to piceous. Clypeus concave, rather abruptly, not deeply emarginate, moderately reflexed; punctures moderate-

ly coarse, evenly placed, denser at base, not deeply impressed; suture sinuate. Frons convex; less densely, more irregularly punctate than base of clypeus. Antennae composed of ten segments. Pronotum convex, widest in front of middle, sides angulate, vaguely indented; punctures evenly placed, feebly impressed, not so dense as on frons. Tooth of claw moderately strong, median. Elytra rugulose, punctures similar to those on pronotum, not so coarse or so deeply impressed; sutural, discal, and submarginal costae prominent and narrow.

Length, 19-24 mm.; width, 10-12 mm.

Male: Antennal club slightly longer than stem. Abdomen broadly flattened at middle; penultimate ventral segment with arcuate, transverse ridge not reaching hind margin, overhanging at ends, roughened at middle; last ventral segment with smooth median depression, apex broadly, not deeply emarginate. Hind tibia obliquely truncate; upper spur flattened, lanceolate, slightly curved, subacute; lower spur fixed, broad, lanceolate, curved, obtuse, two-thirds length of upper.

Female: Antennal club much shorter than funicle. Abdomen with vague, median depression; penultimate ventral segment transversely depressed at apex; last ventral segment with apex broadly, not deeply emarginate.

Locality records are: Marquette, Leon, Ames, Edgewood, Manchester, Ruthven, Farmersburg, Arlington, Dubuque, Iowa City, Mt. Pleasant, Chariton, New Hampton, Van Buren County, and Davis County. Hazel, wild plum, white oak, quaking aspen, elm, willow, large-toothed aspen, linden, privet, and poplar are the known host plants in Iowa.

Phyllophaga drakii (Kirby)

(Plate V, fig. 18)

1837   *Rhizotrogus drakii* Kirby, Fauna Br.-Am., pt. 4: 133.
1850   *Lachnosterna consimilis* Le Conte, Agassiz, Lake Superior: 226.
1853   *Phyllophaga consimilis* Melsheimer, Cat. Coleop. U. S.: 59.
1856   *Lachnosterna drakii* Le Conte, Acad. Phil., Jour., (2), 3: 245.
1884   *Lachnosterna consimilis* Casey, N. A. Coleop., pt. 1, 39.
1884   *Lachnosterna drakei* Casey, N. A. Coleop., pt. 1: 39.
1888   *Lachnosterna grandis* Smith, Ins. Life, 1: 181.
1889   *Lachnosterna grandis* Smith, U. S. Nat. Mus., Proc., 11: 505.
1912   *Lachnosterna drakei* Junk, Coleop. Cat., pt. 49: 190.
1916   *Lachnosterna grandis* Davis, Jour. Econ. Ent., 9: 275.
1916   *Phyllophaga drakii* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916   *Phyllophaga drakii* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 232.
1927   *Phyllophaga drakii* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 44.
1928   *Phyllophaga drakei* Sim, N. J. Dept. Agr., Circ. 145: 25.

Body oblong, shiny, light to dark brown. Clypeus concave, abruptly, rather deeply emarginate, moderately reflexed; densely and finely punctate; suture subangulate. Frons convex; punctures similar to those on clypeus, slightly coarser. Antennae composed of ten segments. Pronotum convex, widest in front of middle, sides arcuate, entire; punctures irregularly placed, much finer, sparser, and not so deeply impressed as on frons. Tooth of claw median, long and strong. Elytra vaguely rugulose, more closely and finely punctate than pronotum; sutural costae narrow, strong, discal, and submarginal costae indistinct.

Length, 26-27 mm.; width, 12-14 mm.

Male: Antennal club longer than stem. Abdomen broadly flattened at middle; penultimate ventral segment with transverse ridge roughened

at middle; overhanging at ends; last ventral segment with median, roughened depression, apex sinuous. Hind tibia obliquely truncate; upper spur slender, lanceolate, slightly curved, subacute; lower spur fixed, slender, lanceolate, acute, two-thirds length of upper.

Female: Antennal club much shorter than funicle. Penultimate ventral segment with vague, transverse depression at apex extending obliquely to base on either side; last ventral segment convex, apex broadly emarginate.

This large species has been collected at Ames, Central City, Dyersville, Manchester, Farmersburg, Arlington, Dubuque, Iowa City, Chariton, Oakland, New Hampton, Grinnell, Cerro Gordo County, and Van Buren County. The food plants are white oak, wild plum, hazel, poplar, willow, birch, and large-toothed aspen.

Phyllophaga barda (Horn)

(Plate V, fig. 17)

1887 *Lachnosterna barda* Horn, Am. Ent. Soc., Trans., **14**: 248.
1889 *Lachnosterna barda* Smith, U. S. Nat. Mus., Proc., **11**: 507.
1916 *Phyllophaga barda* Glasglow, Ill. Nat. Hist., Bul. **11**: 373.
1916 *Phyllophaga barda* Forbes, Ill. Agr. Expt. Sta., Bul. **186**: 325.
1927 *Phyllophaga barda* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 47.
1928 *Phyllophaga barda* Sim, N. J. Dept. Agr., Circ. **145**: 31.

Body oblong, moderately shiny, dark brown to piceous. Clypeus subconcave, rather broadly and deeply emarginate; punctures coarse, not deeply impressed; suture sinuate. Frons convex; more coarsely punctate than clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides angulate, irregular; punctures variolate. Tooth of claw median, strong. Elytra rugulose, less coarsely, more densely punctate than pronotum; sutural costae broad, strong, discal, and submarginal costae broad, feebly elevated.

Length, 21-22 mm.; width, 10-12 mm.

Male: Antennal club slightly shorter than stem. Abdomen broadly flattened at middle; penultimate ventral segment with broad, strongly arcuate carina, deeply excavated behind; last ventral segment concave, apex feebly emarginate. Hind tibia squarely truncate; upper spur lanceolate, curved, obtuse; lower spur fixed, broad, linear, obtuse, two-thirds length of upper.

Female: Antennal club shorter than funicle. Abdomen vaguely flattened at middle; penultimate ventral segment deeply, broadly, and transversely depressed; last ventral segment convex, apex rather broadly and deeply emarginate.

Only two specimens have been taken in Iowa, both of which were secured by Prof. H. E. Jaques at Mt. Pleasant. There have been no food plants recorded for this state.

Phyllophaga marginalis (Le Conte)

(Plate V, fig. 19)

1856 *Lachnosterna marginalis* Le Conte, Acad. Phil., Jour., (2), **3**: 250.
1887 *Lachnosterna marginalis* Horn, Am. Ent. Soc., Trans., **14**: 250.
1887 *Lachnosterna marginalis* Horn, Ent. Am., **3**: 144.
1889 *Lachnosterna marginalis* Smith, U. S. Nat. Mus., Proc., **11**: 508.
1916 *Phyllophaga marginalis* Glasglow, Ill. Nat. Hist., Bul. **11**: 272.
1928 *Phyllophaga marginalis* Sim, N. J. Dept. Agr., Circ. **145**: 39.
1928 *Phyllophaga marginalis* Luginbill, Ann. Ent. Soc. Am., **21**: 70.

Body oblong, shiny, rufocastaneous to piceous. Clypeus subconcave, rather abruptly and deeply emarginate, narrowly reflexed; coarsely and deeply punctuate; suture sinuate. Frons convex; punctured similar to clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest back of middle, sides angulate, crenate; punctures of thorax very sparse, especially on disc, coarse and deeply impressed. Tooth of claw median, long. Elytra rugulose, punctures moderately dense, fine, and deeply impressed; sutural costae strong, discal costae rather broad, distinct, submarginal costae strong.

Length, 16-21 mm.; width, 8-11 mm.

Male: Antennal club longer than stem. Abdomen broadly flattened at middle; penultimate ventral segment with short, strongly arcuate ridge; last ventral segment with median depression, apex entire. Hind tibia obliquely truncate; upper spur long, slightly curved, acute; lower spur fixed, broad, acute, two-thirds length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment transversely and laterally depressed; last ventral segment subdepressed, apex broadly, feebly emarginate.

Specimens have been taken on bur oak, gooseberry, and hazel at Hampton, Leon, Marquette, and Iowa City.

Phyllophaga spreta (Horn)

(Plate VI, fig. 20)

1887 *Lachnosterna spreta* Horn, Am. Ent. Soc., Trans., 14: 250.
1889 *Lachnosterna spreta* Smith, U. S. Nat. Mus., Proc., 11: 508.
1916 *Phyllophaga spreta* Glasglow, Ill. Nat. Hist., Bul. 11: 373.

Specimens of this species were not available so the following is a copy of Horn's original description.

"Oblong, elytra slightly wider at middle, castaneous or fuscous, shining. Clypeus feebly emarginate, margin very narrowly reflexed, densely and moderately coarsely punctured, front rather more coarsely but less densely. Thorax narrower in front, sides posteriorly nearly parallel, in front oblique, the margin entire, with short distinct ciliae, disc moderately convex, the punctures small, sparsely but equally placed, a slight depression of the base on each side. Elytral punctures equal to those of the thorax, more closely placed, surface slightly rugulose on each side of the suture, the costae distinct but feebly elevated, the submarginal distinct posteriorly. Pygidium sparsely punctate, smoother near the apex. Metasternum densely punctate, the hair moderately long and close; sides of abdomen with sparse punctures bearing short hairs. Claws curved, the tooth moderate in size and median ♂. Last joint of maxillary palpi short, fusiform, not impressed. Length .66-.72 inch; 16.5-18 mm.

"Male.—Antennal club nearly a third longer than the entire stem. Abdomen slightly flattened at middle, penultimate segment with a short, feeble elevated, transverse ridge a short distance in front of the posterior margin. Last segment very slightly concave. Inner spur of hind tibia two-thirds the length of the outer and broader.

"Variations.—The two male specimens before me do not vary, except slightly in color and size.

"In this species the clypeus is more feebly emarginate than usual in those with the punctures of its surface dense and the border narrowly reflexed. On the other hand the antennal club of the male is unusually long,

exceeding that of any species of the fusca group. The facies and sculpture are very like a small *fusca*."

A very rare species known only from the type specimens. (Iowa and Maryland, Horn, 1887).

Phyllophaga fraterna Harris

(Plate VI, fig. 21)

1841 *Phyllophaga fraterna* Harris, Rpt. Ins. Inj. Veg.: 29.
1850 *Ancylonycha fraterna* Blanchard, Cat. Coleop. Ent., 1: 133.
1853 *Phyllophaga fraterna* Melsheimer, Cat. Coleop. U. S.: 59.
1855 *Ancylonycha cognata* Burmeister, Handb. Ent., 4: 322.
1856 *Lachnosterna cognata* Le Conte, Acad. Phil., Jour., (2), 3: 248.
1856 *Lachnosterna fraterna* Le Conte, Acad. Phil., Jour., (2), 3: 249.
1887 *Lachnosterna fraterna* Horn, Am. Ent. Soc., Trans., 14: 251.
1887 *Lachnosterna cognata* Horn, Am. Ent. Soc., Trans., 14: 252.
1887 *Lachnosterna fraterna* Horn, Ent. Am., 3: 144.
1889 *Lachnosterna fraterna* Smith, U. S. Nat. Mus., Proc., 11: 508.
1889 *Lachnosterna nova* Smith, U. S. Nat. Mus., Proc., 11: 508.
1889 *Lachnosterna nova* Smith, Ent. Am., 5: 95.
1889 *Lachnosterna nova* Smith, U. S. Nat. Mus., Proc., 11: 509.
1916 *Lachnosterna fraterna* Davis, Jour. Econ. Ent., 9: 274.
1916 *Phyllophaga fraterna* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916 *Phyllophaga fraterna* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 228.
1927 *Phyllophaga fraterna* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 48.
1928. *Phyllophaga fraterna* Sim, N. J. Dept. Agr., Circ. 145: 36.

Body elongate, sides nearly parallel, shiny, rufocastaneous to piceous. Clypeus flat, with abrupt, moderately deep emargination, rather broadly reflexed; punctures moderately coarse, dense, deeply impressed; suture subangulate. Frons convex; punctures similar to those on clypeus, slightly coarser. Antennae composed of ten segments. Pronotum convex, widest at middle; sides subangulate, feebly crenate; punctures irregularly placed, sparser, coarser, and more feebly impressed than on pronotum. Tooth of claw median, strong. Elytra rugulose, more finely and closely punctate than pronotum; sutural costae broad, strong, discal and submarginal costae indistinct.

Length, 15-18 mm.; width, 7-8 mm.

Male: Antennal club subequal to funicle. Abdomen depressed at middle; penultimate ventral segment with roughened, feebly arcuate ridge; last ventral segment concave, apex feebly emarginate. Hind tibia obliquely truncate; upper spur long, lanceolate, obtuse; lower spur fixed, broad, curved, subacute, two-thirds length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with transverse depression at apex; last ventral segment convex, apex with broad, shallow emargination.

This species has been collected at Iowa City, Columbus Junction, Dyersville, Keosauqua, Mt. Pleasant, and Jackson County. White oak and hazel are the host plants.

Phyllophaga fosteri (Burmeister)

(Plate VI, fig. 22)

1855 *Ancylonycha fosteri* Burmeister, Handb. Ent., 4: 325.
1856 *Lachnosterna semicribrata* Le Conte, Acad. Phil., Jour., (2), 3: 247.
1856 *Lachnosterna lugubris* Le Conte, Acad. Phil., Jour., (2), 3: 248.
1856 *Lachnosterna lutescens* Le Conte, Acad. Phil., Jour., (2), 3: 249.
1887 *Lachnosterna semicribrata* Horn, Am. Ent. Soc., Trans., 14: 252.

1887   *Lachnosterna lutescens* Horn, Ent. Am., **3**: 144.
1887   *Lachnosterna politula* Horn, Am. Ent. Soc., Trans., **14**: 248.
1887   *Lachnosterna fosteri* Horn, Am. Ent. Soc., Trans., **14**: 252.
1889   *Lachnosterna semicribrata* Smith, U. S. Nat. Mus., Proc., **11**: 508.
1889   *Lachnosterna fosteri* Smith, U. S. Nat. Mus., Proc., **11**: 508.
1889   *Lachnosterna nova* Smith, Ent. Am., **5**: 95.
1889   *Lachnosterna nova* Smith, U. S. Nat. Mus., Proc., **11**: 509.
1916   *Phyllophaga fosteri* Glasglow, Ill. Nat. Hist., Bul. 11: 372.
1916   *Phyllophaga fosteri* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 233.
1927   *Phyllophaga fosteri* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 50.
1928   *Phyllophaga fosteri* Luginbill, Ann. Ent. Soc. Am., **21**: 74.
1928   *Phyllophaga fosteri* Sim, N. J. Dept. Agr., Circ. 145: 39.

Body oblong, moderately shiny, rufocastaneous. Clypeus flat, deeply, almost abruptly emarginate, feebly, rather broadly reflexed; punctures moderately coarse, deeply impressed; suture subangulate. Frons subconvex; punctures similar to those on clypeus, not so dense. Antennae composed of nine segments. Pronotum convex, widest at middle, sides arcuate, crenate; punctures irregular, much coarser, not so dense or deeply impressed as on frons. Tooth of claw median, strong. Elytra with punctures finer, more closely placed, not so deeply impressed as on pronotum; sutural costae strong, discal costae broad, feebly elevated, submarginal costae narrow, strong.

Length, 14-18 mm.; width, 8-10 mm.

Male: Antennal club subequal to funicle. Abdomen broadly flattened at middle; penultimate ventral segment with moderately arcuate roughened ridge; last ventral segment with smooth cupuliform depression, apex feebly emarginate. Hind tibia squarely truncate; upper spur lanceolate, slightly curved, obtuse; lower spur fixed, broad, acute, two-thirds length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with narrow, transverse depression at apex extending obliquely forward; last ventral segment strongly elevated at base, apex feebly, broadly emarginate.

Collected at Marquette, Iowa City, and Mt. Pleasant. The food plants have not been reported for Iowa.

Phyllophaga corrosa (Le Conte)

(Plate VI, fig. 23)

1856   *Lachnosterna corrosa* Le Conte, Acad. Phil., Jour., (2), **3**: 249.
1856   *Lachnosterna affinis* Le Conte, Acad. Phil., Jour., (2), **3**: 256.
1887   *Lachnosterna affinis* Horn, Am. Ent. Soc., Trans., **14**: 233.
1887   *Lachnosterna affinis* Horn, Ent. Am., **3**: 144.
1887   *Lachnosterna corrosa* Horn, Ent. Am., **3**: 144.
1889   *Lachnosterna affinis* Smith, U. S. Nat. Mus., Proc., **11**: 498.
1916   *Phyllophaga corrosa* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916   *Phyllophaga corrosa* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 232.
1925   *Phyllophaga corrosa* Hayes, Kans. Agr. Expt. Sta., Tech. Bul. 16: 45.
1928   *Phyllophaga corrosa* Sim, N. J. Dept. Agr., Circ. 145: 24.

Body oblong, moderately shiny, castaneous to piceous. Clypeus concave, rather abruptly and deeply emarginate, narrowly reflexed; coarsely and closely punctate; suture sinuate. Frons subconvex; punctuation similar to that of clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides angulate, serrate; more coarsely, less closely punctate than frons. Mesosternum with sparse vestiture of moderately long, yellowish hair. Tooth of claw median, slender and long. Elytra rugulose, more closely, less coarsely punctate than pronotum; sutu-

ral costae wide and strong, discal costae indistinct, submarginal costae indistinct in posthumeral region.

Length, 17-20 mm.; width, 8-10 mm.

Male: Antennal club shorter than stem. Abdomen flattened medially; penultimate ventral segment with feebly arcuate, roughened ridge, slightly excavated behind; last ventral segment with smooth, median depression, with transverse ridge at base, apex feebly and broadly emarginate. Hind tibia vaguely excavated at base of lower spur; upper spur flattened, elliptical, slightly curved, obtuse; lower spur fixed, subacuminate, curved, two-thirds length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with oblique, lateral depression; last ventral segment with deep, subtriangular, median depression, apex excavated on each side of middle leaving broad, median tooth.

A few individuals have been taken at Ames, Dyersville and Iowa City. Feeds on white oak and hawthorne.

Phyllophaga rugosa (Melsheimer)

(Plate VII, fig. 24)

1846 *Ancylonycha rugosa* Melsheimer, Acad. Phil., Proc., 3: 140.
1853 *Phyllophaga rugosa* Melsheimer, Cat. Coleop. U. S.: 59.
1855 *Ancylonycha rugosa* Burmeister, Handb. Ent., 4, pt. 2: 328.
1856 *Lachnosterna rugosa* Le Conte, Acad. Phil., Jour., (2), 3: 252.
1887 *Lachnosterna rugosa* Horn, Am. Ent. Soc., Trans. 14: 259.
1887 *Lachnosterna rugosa* Horn, Ent. Am., 3: 143.
1889 *Lachnosterna rugosa* Smith, U. S. Nat. Mus., Proc., 11: 513.
1916 *Lachnosterna rugosa* Davis, Jour. Econ. Ent., 9: 277.
1916 *Phyllophaga rugosa* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916 *Phyllophaga rugosa* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 226.
1928 *Phyllophaga rugosa* Sim, N. J. Dept. Agr., Circ. 145: 18.

Body oblong, shiny, rufocastaneous to piceous. Clypeus flat, deeply, moderately broadly emarginate, punctures coarse, deeply impressed; suture angulate. Frons convex, more coarsely and deeply punctate than clypeus. Antennae composed of ten segments. Pronotum convex, widest at middle, sides angulate, vaguely crenate; irregularly and variolately punctate. Tooth of claw median, strong. Elytra rugulose, punctures similar to those on clypeus, not so dense; sutural costae broad, strong, discal and submarginal costae broad, feebly elevated.

Length, 18-23 mm.; width, 9-11 mm.

Male: Antennal club slightly longer than funicle. Abdomen broadly flattened at middle; penultimate ventral segment with strongly arcuate ridge, roughened at middle; last ventral segment concave, smooth, apex abruptly and deeply emarginate. Hind tibia obliquely truncate; upper spur lanceolate, obtuse; lower spur fixed, curved, acute, two-thirds length of upper.

Female: Antennal club shorter than funicle. Abdomen vaguely flattened at middle; penultimate ventral segment with transverse depression; last ventral segment feebly concave, apex broadly, not deeply emarginate.

Extremely abundant: Des Moines, Ames, Hampton, Leon, Amana, Marquette, Ruthven, Maquoketa, Guttenburg, Dubuque, Dyersville, Pleasant Valley, McGregor, Algona, Sioux City, Davenport, Atlantic, Manchester, Marshalltown, Arlington, Iowa City, Mt. Pleasant, Muscatine, Sioux City, Clermont, Oakland, Keokuk, Grinnell, Marion County, Monona County,

Sioux County, Linn County, Wapello County, Mills County, Lyon County, Boone County, Page County, Pottawattamie County, Davis County, Cedar County, Cherokee County, and Van Buren County. Collections have been made from buckeye, apple, linden, birch, walnut, silver poplar, privet, cherry, box elder, mock orange, Cornus, Caragana, bur oak, hickory, elm, willow, ash, butternut, quaking aspen, wild plum, hawthorne, red oak, white oak, hackberry, large-toothed aspen, hazel, cottonwood, and plum.

Phyllophaga implicita (Horn)

(Plate VII, fig. 25)

1887 *Lachnosterna implicita* Horn, Am. Ent. Soc., Trans., **14**: 262.
1889 *Lachnosterna implicita* Smith, U. S. Nat. Mus., Proc., **11**: 515.
1897 *Lachnosterna minor* Linell, U. S. Nat. Mus., Proc., **18**: 728.
1916 *Lachnosterna implicita* Davis, Jour. Econ. Ent., **9**: 276.
1916 *Phyllophaga implicita* Glasglow, Ill. Nat. Hist., Bul. **11**: 373.
1916 *Phyllophaga implicita* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 221.
1927 *Phyllophaga implicita* Langston, Miss. Agr. Expt. Sta., Tech. Bul. **15**: 57.
1928 *Phyllophaga implicita* Sim, N. J. Dept. Agr., Circ. 145: 42.

Body ovate, moderately shiny, brown to piceous, head and pronotum darker. Clypeus flat, deeply and abruptly emarginate, moderately reflexed; punctures moderately coarse, not deeply impressed; suture sinuate. Frons convex; punctures denser, slightly coarser than on clypeus. Antennae composed of ten segments. Pronotum convex, widest in front of middle, sides angulate, feebly crenate; punctures not so coarse, much sparser than on frons. Tooth of claw slightly intramedian. Elytra rugulose, punctures finer than on pronotum, not so deeply impressed; sutural costae wide, strong, discal, and submarginal costae indistinct.

Length, 14-18 mm.; width, 8-10 mm.

Male: Antennal club subequal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with strongly arcuate, feebly elevated, roughened transverse ridge; last ventral segment convex, apex broadly, not deeply emarginate. Hind tibia obliquely truncate; upper spur lanceolate, subacute; lower spur fixed, arcuate, one-half length of upper.

Female: Antennal club subequal to funicle. Penultimate ventral segment with feeble transverse depression; last ventral segment flattened, apex rather broadly and deeply emarginate.

Occurs almost everywhere: Ames, Des Moines, Keokuk, Central City, Hampton, Ruthven, Fort Dodge, Marquette, Maquoketa, Columbus Junction, Algona, Pleasant Valley, Iowa City, Cylinder, Sioux City, Dubuque, Davenport, Atlantic, Farmersburg, Bryant, Red Oak, Sharpsburg, Humbolt, Marshalltown, Grinnell, Clermont, Muscatine, Oakland, Creston, Boone, New Hampton, Morning Sun, Mt. Union, Keosauqua, Mt. Pleasant, Wapello County, Monroe County, Lee County, Boone County, Jefferson County, Des Moines County, Davis County, and Madison County. Collected from bur oak, hickory, elm, ash, butternut, red oak, white oak, hackberry, large-toothed aspen, quaking aspen, willow, cherry, hazel, poplar, gooseberry Caragana, birch, and silver poplar.

Phyllophaga balia (Say)

(Plate VII, fig. 27)

1825 *Melolontha balia* Say, Acad. Phil., Jour., **5**: 194, in Le Conte ed., 1889, p. 297.
1826 *Phyllophaga balia* Harris, Mass. Agr. Jour. and Rpts., **10**: 1-12.
1853 *Phyllophaga balia* Melsheimer, Cat. Coleop. U. S.: 59.

1855 *Ancylonycha comata* Burmeister, Handb. Ent., **4**, pt. 2: 337.
1856 *Lachnosterna balia* Le Conte, Acad. Phil., Jour., (2), **3**: 255.
1887 *Lachnosterna balia* Horn, Am. Ent. Soc., Trans., **14**: 262.
1887 *Lachnosterna comata* Horn, Ent. Am., **3**: 143.
1889 *Lachnosterna balia* Smith, U. S. Nat. Mus., Proc., **11**: 516.
1916 *Phyllophaga balia* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 235.
1916 *Phyllophaga balia* Glasglow, Ill. Nat. Hist., Bul. 11: 371.

Body elongate, moderately shiny, dark brown to piceous, head and thorax darker. Clypeus flat, broadly, moderately deeply emarginate, narrowly reflexed; punctures coarse, moderately closely placed, rather deeply impressed; suture sinuous. Frons subconvex; more coarsely and irregularly punctate than clypeus, with sparse vestiture of long erect hair. Antennae normally composed of nine segments. Pronotum convex, widest at middle, sides subarcuate, vaguely indented; punctures coarser, sparser and not so deeply impressed as on frons, more densely punctate at sides. Tooth of claw strong, median. Elytra rugulose, punctures indistinct; sutural costae strong, discal and submarginal costae indistinct.

Length, 15-16 mm.; width, 8-9 mm.

Male: Antennal club equal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with broad, obtusely arcuate, roughened ridge, deeply excavated behind; last ventral segment with a smooth, cupuliform, median depression, transversely elevated at base, apex entire. Hind tibia obliquy truncate; upper spur slender, lanceolate, subacute, lower spur fixed, lanceolate, subacute, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with moderately deep, transverse depression, apex of last ventral segment feebly excavated at sides leaving short, median, triangular tooth.

This species has been collected at Marquette, Ames, Dyersville, Farmersburg, Dubuque, Iowa City, and Mt. Pleasant. Food plants include white oak, willow, hazel, box elder, and birch.

Phyllophaga vilifrons (Le Conte)

(Plate VII, fig. 26)

1856 *Lachnosterna vilifrons* Le Conte, Acad. Phil., Jour., (2), **3**: 255.
1856 *Lachnosterna hirticeps* Le Conte, Acad. Phil., Jour., (2), **3**: 255.
1887 *Lachnosterna hirticeps* Horn, Ent. Am., **3**: 145.
1887 *Lachnosterna villiforns* Horn, Am. Ent. Soc., Trans., **14**: 144.
1889 *Lachnosterna villifrons* Smith, U. S. Nat. Mus., Proc., **11**: 516.
1916 *Phyllophaga villifrons* Glasglow, Ill. Nat. Hist., Bul. 11: 372.
1916 *Phyllophaga villifrons* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 234.
1928 *Phyllophaga villifrons* Luginbill, Ann. Ent. Soc. Am., 21: 89.

Body elongate, shiny, rufocastaneous. Clypeus flat, abruptly, rather deeply emarginate, moderately reflexed; punctures coarse, deeply impressed; suture angulate. Frons convex; punctures similar to those on clypeus, less densely placed. Antennae composed of nine segments. Pronotum convex, widest at middle, sides arcuate, crenate at base; punctured similar to frons. Tooth of claw median, strong. Elytra more densely and more finely punctate than pronotum; sutural costae strong, discal and submarginal costae indistinct.

Length, 14-16 mm.; width, 7-9 mm.

Male: Antennal club equal to stem. Abdomen broadly flattened at middle; penultimate ventral segment with broad, feebly arcuate, roughened ridge; last ventral segment longitudinally depressed, apex feebly emarginate.

Hind tibia obliquely truncate; upper spur flattened, lanceolate, acute; lower spur fixed, broad, slightly curved, obtuse, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment vaguely and transversely depressed, with broad, roughened depression at sides; last ventral segment flat, apex feebly and broadly emarginate.

This rare species has been taken at McGregor, Ames, Dubuque, and Iowa City on linden and birch.

Phyllophaga nitida (Le Conte)

(Plate VIII, fig. 30)

1856 *Lachnosterna nitida* Le Conte, Acad. Phil., Jour., (2), **3**: 256.
1887 *Lachnosterna nitida* Horn, Ent. Am., **3**: 145.
1887 *Lachnosterna limula* Horn, Am. Ent. Soc., Trans., **14**: 264.
1889 *Lachnosterna nitida* Smith, U. S. Nat. Mus., Proc., **11**: 516.
1889 *Lachnosterna innominata* Smith, Ent. Am., **5**: 98.
1916 *Phyllophaga nitida* Glasglow, Ill. Nat. Hist., Bul. 11: 372.
1916 *Phyllophaga nitida* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 233.
1928 *Phyllophaga nitida* Sim, N. J. Dept. Agr., Circ. 145: 33.

Body elongate, shiny, dark brown. Clypeus flat, abruptly, rather deeply emarginate, punctures coarse, deeply impressed; suture feebly sinuate. Frons convex; punctures similar to those on clypeus, but coarser, Antennae composed of nine segments. Pronotum convex, widest at middle, sides arcuate, irregular; punctures similar to those on frons, sparser and not so deeply impressed. Tooth of claw median, strong. Elytra rugulose, punctures much finer and denser than on pronotum; sutural costae strong, discal and submarginal costae narrow, feebly elevated.

Length, 20-21 mm.; width, 8-9 mm.

Male: Antennal club shorter than stem. Abdomen moderately depressed at middle; penultimate ventral segment with transverse ridge, strongly elevated at sides, divided at middle; last ventral segment with broad, median depression, apex feebly and broadly emarginate. Hind tibia obliquely truncate; upper spur lanceolate, curved, acute; lower spur fixed, broad, acute, two-thirds length of upper.

Female: Antennal club shorter than funicle. Abdomen with vague, median depression; penultimate ventral segment feebly, transversely depressed; last ventral segment slightly flattened, apex irregular, broadly and feebly emarginate.

The locality records include Hampton, Ames, Farmersburg, Dyersville and Dubuque. Feeds on hazel, white oak, linden, privet, cornus, and birch.

Phyllophaga hirticula (Knoch)

(Plate VIII, fig. 29)

1801 *Melolontha hirticula* Knoch, Neue Beytr. Ins., **1**: 79.
1813 *Melolontha hirsuta* Say, Acad. Phil., Jour., **3**: 243, in Le Conte ed., **2**: 142 (not Knoch).
1817 *Melolontha hirticula* Schönherr, Syn. Ins., **1**, (3): 173.
1826 *Phyllophaga hirticula* Harris, Mass. Agr. Jour. and Rpts., **10**: 1-12.
1850 *Ancylonycha crenulata* Blanchard, Cat. Coll. Ent., **1**: 133.
1853 *Phyllophaga hirticula* Melsheimer, Cat. Coleop. U. S.: 59.
1855 *Ancylonycha hirticula* Burmeister, Handb. Ent., **4**: 327.
1856 *Lachnosterna hirticula* Le Conte, Acad. Phil., Jour., (12), **3**: 254.
1873 *Lachnosterna crenulata* Le Conte, Acad. Phil., Proc.: 330.
1887 *Lachnosterna hirticula* Horn, Am. Ent. Soc., Trans., **14**: 266.
1887 *Lachnosterna hirticula* Horn, Ent. Am., **3**: 143.

1889   *Lachnosterna hirticula* Smith, U. S. Nat. Mus., Proc., **11**: 516.
1916   *Lachnosterna hirticula* Davis, Jour. Econ. Ent., **9**: 275-276.
1916   *Phyllophaga hirticula* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916   *Phyllophaga hirticula* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 219.
1927   *Phyllophaga hirticula* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 58.
1928   *Phyllophaga hirticula* Luginbill, Ann. Ent. Soc. Am., **21**: 57.

Body oblong, moderately shiny, dark brown, with sparse vestiture of both long and short hairs. Clypeus flat, deeply, and abruptly emarginate, moderately reflexed; punctures coarse, rather deeply impressed; suture sinuate. Frons convex; punctures similar to those on clypeus. Antennae composed of ten segments. Pronotum irregularly convex, widest at middle, sides arcuate, coarsely serrate; punctures variolate, moderately dense. Tooth of claw median, strong. Elytra strongly rugulose, punctures finer than on frons; long, erect hairs in rows along costae; sutural costae broad, strong, discal and submarginal costae feebly elevated, rather broad.

Length, 16-19 mm.; width, 8-11 mm.

Male: Antennal club longer than funicle. Abdomen broadly flattened at middle; penultimate ventral segment with broad, arcuate, roughened, feebly elevated ridge; last ventral segment with broad, rather deep, median depression, apex with broad, moderately deep, emargination. Hind tibia obliquely truncate; upper spur long, curved, lanceolate, subacute; lower spur broad, curved, lanceolate, acute, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with vague, transverse depression; last ventral segment flattened, with semi-circular depression at apex, apex broadly and shallowly emarginate.

Very abundant, taken at Ames, Leon, Hampton, Maquoketa, Guttenburg, Dubuque, Marquette, Dyersville, Onawa, Missouri Valley, Davenport, Mt. Pleasant, Clermont, Chariton, Muscatine, Washington County, Marion County, Monroe County, Des Moines County, Van Buren County, and Wapello County. Elm, bur oak, hickory, willow, ash, butternut, shingle oak, hawthorne, red oak, white oak, gooseberry, hazel, and quaking aspen are the host plants.

Phyllophaga ilicis (Knoch)

(Plate VIII, fig. 28)

1801   *Melolontha ilicis* Knoch, Neue Beytr. Ins., 1: 71.
1830   *Melolontha porcina* Hentz, Am. Soc. Phil., Trans., (2), **3**: 253.
1850   *Ancylonycha ilicis* Blanchard, Cat. Coll. Ent., 1: 133.
1853   *Phyllophaga ilicis* Melsheimer, Cat. Coleop. U. S.: 59.
1855   *Ancylonycha ilicis* Burmeister, Handb. Ent., 4, pt. 2: 326 (not Knoch).
1855   *Ancylonycha fimbriata* Burmeister, Handb. Ent., **4**: 326.
1856   *Lachnosterna ilicis* Le Conte, Acad. Phil., Jour., (2), **3**: 253.
1856   *Lachnosterna ciliata* Le Conte, Acad. Phil., Jour., (2), **3**: 253.
1856   *Lachnosterna subtonsa* Le Conte, Acad. Phil., Jour., (2), **3**: 254.
1887   *Lachnosterna ilicis* Horn, Am. Ent. Soc., Trans., **14**: 268.
1887   *Lachnosterna ilicis* Horn, Ent. Am., **3**: 144.
1887   *Lachnosterna ciliata* Horn, Am. Ent. Soc., Trans., **14**: 269.
1887   *Lachnosterna ciliata* Horn, Ent. Am., **3**: 144.
1887   *Lachnosterna subtonsa* Horn, Ent. Am., **3**: 144.
1887   *Lachnosterna fimbriata* Horn, Ent. Am., **3**: 143.
1889   *Lachnosterna ilicis* Smith, U. S. Nat. Mus., Proc., **11**: 517.
1912   *Lachnosterna ilicis* var. *Burmeisteri* Junk, Coleop. Cat., pt. 49: 193.
1916   *Lachnosterna ilicis* Davis, Jour. Econ. Ent., **9**: 276.
1916   *Phyllophaga ilicis* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1916   *Phyllophaga ilicis* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 230.

1927 *Phyllophaga ilicis* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 61.
1928 *Phyllophaga ilicis* Luginbill, Ann. Ent. Soc. Am., 21: 62.

Body oblong, subopaque, castaneous, with vestiture of moderately long, recumbent hair. Clypeus flat, abruptly and deeply emarginate, moderately reflexed; densely, coarsely, and deeply punctate; suture subangulate. Frons subconvex; punctures coarser, not so dense as on clypeus. Antennae composed of ten segments. Pronotum convex, widest at middle, sides subangulate, crenate; punctures coarser, not so closely placed, more deeply impressed than on frons. Tooth of claw median, long. Elytra finely rugulose, punctures much finer than on pronotum; sutural, discal, and submarginal costae wide, feebly elevated.

Length, 19-23 mm.; width, 10-12 mm.

Male: Antennal club slightly longer than funicle. Abdomen with moderately wide depression at middle; penultimate ventral segment with arcuate ridge feebly elevated at middle; last ventral segment concave, apex broadly and feebly emarginate. Hind tibia obliquely truncate; upper spur long, lanceolate, curved, obtuse; lower spur fixed, slightly curved, subacute, one-half length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment with deep, transverse depression; last ventral segment convex, apex rather deeply and abruptly emarginate.

Marquette, Leon, Hampton, Maquoketa, Guttenberg, Dubuque, Dyersville, Arlington, Ames, Mt. Pleasant, Marengo, Clayton County, Buchanan County, Delaware County, Jones County, Woodbury County, Van Buren County, Lee County, Iowa County, Scott County, Jefferson County, Jackson County, and Appanoose County. Taken on hickory, ash, butternut, shingle oak, hawthorne, red oak, white oak, large-toothed aspen, hazel, Cornus, and linden.

Phyllophaga crenulata (Froelich)

(Plate IX, fig. 31)

1792 *Melolontha crenulata* Froelich, Natur. Stueck, 26: 94.
1817 *Melolontha georgicana* Gyllenhall, Syn. Ins., 1: 77.
1826 *Phyllophaga georgicana* Harris, Mass. Agr. Jour. and Rpts., 10: 1-12.
1850 *Ancylonycha crenulata* Blanchard, Cat. Coll. Ent., 1: 133.
1853 *Phyllophaga georgicana* Melsheimer, Cat. Coleop. U. S.: 59.
1855 *Ancylonycha crenulata* Burmeister, Handb. Ent., 4: 327.
1856 *Lachnosterna crenulata* Le Conte, Acad. Phil., Jour., (2), 3: 258.
1887 *Lachnosterna crenulata* Horn, Am. Ent. Soc., Trans., 14: 272.
1887 *Lachnosterna crenulata* Horn, Ent. Am., 3: 143.
1889 *Lachnosterna crenulata* Smith, U. S. Nat. Mus., Proc., 11: 518.
1916 *Lachnosterna crenulata* Davis, Jour. Econ. Ent., 9: 273-274.
1916 *Phyllophaga crenulata* Glasglow, Ill. Nat. Hist., Bul. 11: 370.
1916 *Phyllophaga crenulata* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 231.
1925 *Phyllophaga crenulata* Hayes, Kans. Agr. Expt. Sta., Tech. Bul. 16: 58-63.
1927 *Phyllophaga crenulata* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 63.
1928 *Phyllophaga crenulata* Luginbill, Ann. Ent. Soc. Am., 21: 60.

Body oblong, moderately shiny, light brown to piceous, with conspicuous vestiture of moderately long, erect hairs. Clypeus subconcave, not broadly, rather abruptly, moderately deeply emarginate, broadly reflexed; punctures coarse, deeply impressed, finer at base; suture angulate. Frons convex; punctures similar to those on clypeus. Antennae composed of ten segments. Pronotum irregularly convex widest in front of middle, sides angulate, coarsely serrate; punctures similar to those on frons, less dense

and not so deeply impressed. Mesosternum with sparse vestiture of long, yellowish hair. Tooth of claw median, long, moderately strong. Elytra with moderately fine, feebly impressed punctures, slightly denser than on pronotum; sutural costae broad; feebly elevated, discal and submarginal costae narrow, indistinct.

Length, 17-20 mm.; width, 9-11 mm.

Male: Antennal club equal to funicle. Abdomen convex; penultimate ventral segment vaguely concave, roughened at middle; last ventral segment smooth, almost glabrous, with median, transverse elevation, apex entire. Hind tibia obliquely truncate; upper spur long, slender, flattened, subacute; lower spur movable, slightly curved, slender, acute.

Female: Antennal club slightly shorter than funicle. Penultimate ventral segment slightly depressed laterally; last ventral segment pubescent, convex, apex entire.

This species has been taken at Ames, Clermont, Pleasant Valley, Columbus Junction, Hampton, Leon, McGregor, Iowa City, Mt. Union, Keokuk, Oakland, Muscatine, Mt. Pleasant, Linn County, Delaware County, Lee County, Appanoose County, and Hamilton County. Bur oak and gooseberry are the host plants.

Phyllophaga quercus (Knoch)

(Plate IX, fig. 32)

1801 *Melolontha quercus* Knoch, Neue Beytr. Ins., 1: 72.
1802 *Melolontha fervida* Illiger, Oliv. Ent., 2: 44.
1817 *Melolontha fervida* Schönherr, Syn. Ins., 1, pt. 3: 171.
1855 *Ancylonycha quercus* Burmeister, Handb. Ent., 4, pt. 2: 340.
1856 *Endrosa quercus* Le Conte, Acad. Phil., Jour., (2), 3: 235.
1887 *Lachnosterna quercus* Horn, Am. Ent. Soc., Trans., 14: 281.
1887 *Lachnosterna quercus* Horn, Ent. Am., 3: 138.
1889 *Lachnosterna quercus* Smith, U. S. Nat. Mus., Proc., 11: 520.
1916 *Phyllophaga quercus* Glasglow, Ill. Nat. Hist., Bul. 11: 371.
1927 *Phyllophaga quercus* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 66.
1928 *Phyllophaga quercus* Luginbill, Ann. Ent. Soc. Am., 21: 85.

Body elongate, pruinose, rufocastaneous. Clypeus concave, abruptly and deeply emarginate, moderately reflexed; punctures coarse, not deeply impressed; suture angulate. Frons convex; more coarsely, less closely punctate, than clypeus. Antennae composed of nine segments. Pronotum convex, widest at middle, sides arcuate, entire; punctures similar to those on frons, not so dense. Tooth of claw median, strong. Elytra punctures similar to those on pronotum, denser; sutural costae strong, narrow, discal, and submarginal costae narrow, indistinct.

Length, 14-16 mm.; width, 7-8mm.

Male: Antennal club equal to stem. Abdomen feebly flattened at middle; penultimate ventral segment vaguely depressed at middle, with broad, roughened area; last ventral segment rough, feebly, transversely impressed, apex vaguely and broadly emarginate. Hind tibia obliquely truncate; upper spur long, linear, slightly curved, obtuse; lower spur movable, slender, curved, obtuse, three-fourths length of upper.

Female: Antennal club shorter than funicle. Penultimate ventral segment transversely and feebly impressed, long, yellowish hairs at sides; last ventral segment small, slightly flattened, apex entire.

This species has been listed by Prof. H. E. Jaques as occurring in Iowa.

Phyllophaga tristis (Fabricius)

(Plate IX, fig. 33)

1781 *Melolontha tristis* Fabricius, Species Ins., 1: 39.
1801 *Melolontha pilosicollis* Knoch, Neue Beytr. Ins., 1: 85.
1817 *Melolontha pilosicollis* Schönherr, Syn. Ins., 1, pt. 3: 177.
1817 *Melolontha tristis* Schönherr, Syn. Ins., 1, pt. 3: 195.
1823 *Melolontha pilosicollis* Say, Acad. Phil., Jour., 3: 243, in Le Conte ed. 2, 1869, p. 143.
1826 *Phyllophaga tristis* Harris, Mass. Agr., Jour. and Rpts., 10: 1-12.
1847 *Trichesthes pilosicollis* Erickson, Natur. Ins. Deutschl., 3: 658.
1850 *Trichestes pilosicollis* Blanchard, Cat. Coll. Ent., 1: 141.
1855 *Trichestes pilosicollis* Burmeister, Handb. Ent., 4, pt. 2: 358.
1856 *Lachnosterna tristis* Le Conte, Acad. Phil., Jour., (2), 3: 261.
1856 *Lachnosterna crinita* Le Conte, Acad. Phil., Jour., (2), 3: 261, (not Burmeister).
1873 *Lachnosterna tristis* Le Conte, Acad. Phil., Proc.: 330.
1887 *Lachnosterna crinita* Horn, Ent. Am., 3: 145.
1887 *Lachnosterna tristis* Horn, Am. Ent. Soc., Trans., 14: 286.
1887 *Lachnosterna tristis* Horn, Ent. Am., 3: 143.
1889 *Lachnosterna tristis* Smith, U. S. Nat. Mus., Proc., 11: 522.
1913 *Lachnosterna tristis* Davis, Jour. Econ. Ent., 6: 277.
1916 *Lachnosterna tristis* Davis, Jour. Econ. Ent., 9: 277.
1916 *Phyllophaga tristis* Glasglow, Ill. Nat. Hist., Bul. 11: 370.
1916 *Phyllophaga tristis* Forbes, Ill. Agr. Expt. Sta., Bul. 186: 229.
1925 *Phyllophaga tristis* Hayes, Kans. Agr. Expt. Sta., Tech. Bul. 16: 66-72.
1927 *Phyllophaga tristis* Langston, Miss. Agr. Expt. Sta., Tech. Bul. 15: 72.
1928 *Phyllophaga tristis* Luginbill, Ann. Ent. Soc. Am., 21: 61.

Body oblong, moderately shiny, testaceous, with sparse vestiture of long, yellowish hair. Clypeus concave, entire; punctures sparse, coarse, rather feebly impressed; suture sinuous. Frons convex; with coarse, close, deeply impressed punctures. Antennae composed of ten segments. Pronotum convex, sides angulate, entire; punctures not so coarse or so closely placed as on frons. Tooth of claw different in male and female. Elytra more closely and finely punctate than pronotum; sutural costae broad, feebly elevated, discal and submarginal costae indistinct.

Length, 12-14 mm.; width, 6-8 mm.

Male: Antennal club subequal to stem. Abdomen vaguely flattened; penultimate ventral segment with short transverse ridge; last ventral segment elevated at base, apex entire. Hind tibia obliquely truncate; upper spur lanceolate, slightly curved, obtuse; lower spur movable, linear, obtuse, four-fifths length of upper. Tooth of claw intramedian.

Female: Antennal club equal to funicle. Penultimate ventral segment with feeble transverse depression; last ventral segment convex, apex entire. Tooth of claw more nearly median.

This species has been collected at Ames, Leon, Hampton, Farmersburg, Dyersville, Dubuque, Mt. Pleasant, Chariton, Muscatine, Iowa City, Allamakee County, Scott County, Appanoose County, Des Moines County, and Van Buren County. Bur oak, elm, willow, and white oak are the known host plants for Iowa.

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EXPLANATION OF PLATES

The illustrations of the male and female organs are original, except number 20, which is a copy of the male genitalia, as drawn by Smith (1889). The sketches were all drawn to the same scale. Arrangements of the drawings for each species of the genus Phyllophaga are as follows: upper left, hind view of the male claspers; lower left, left male clasper; lower right, right male clasper; and the upper right ventral view of female genitalia. Since the penis sheath is not of great specific value, only the distal end of the sheath is figured. The page listed with the figure refers to the description of the species in the text.

PLATE I

PLATE I

PLATE II

PLATE II

PLATE III

PLATE III

PLATE IV

PLATE IV

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PLATE V

PLATE V

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PLATE VI

PLATE VI

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PLATE VII

PLATE VII

PLATE VIII

PLATE VIII

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PLATE IX

PLATE IX

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GROWTH AND SEXUAL MATURITY IN BRAHMA AND LEGHORN FOWL[1]

Nelson F. Waters

Evidence has been offered by Hays (3) that early sexual maturity in Rhode Island Red fowls is dependent in part on two dominant genes, one of which is sex-linked. Hays' hypothesis suggests that the presence of either or both of these dominant genes will produce a bird that normally begins to lay at the age of 215 days or earlier. Warren (11) also finds some evidence of a sex-linked gene for early sexual maturity in a cross between White Leghorns and Rhode Island Reds. This bulletin offers additional information on the inheritance of time of sexual maturity based on a cross between a single comb White Leghorn and Light Brahma fowl.

It is evident that early sexual maturity in the domestic fowl is a desirable character, and that, other things being equal, early maturing pullets will produce in their first laying year a larger number of eggs than late maturing pullets. But it is possible to over-emphasize the importance of early sexual maturity, for Graham (2) finds that early maturing birds weigh less than late maturing birds on attaining sexual maturity. Graham does not state whether the ultimate weight of the early maturing bird is greater or less than that of late maturing birds. Jull (5), using Barred Plymouth Rocks, found that a significant positive correlation exists between the mean weight of the first ten eggs laid in the pullet year and time to sexual maturity. This correlation is shown to be important by the observations of Maw and Maw (7), who find that the earlier in life laying commences, the longer is the time required to attain production of eggs of standard size. Further, these same authors have shown that the mean annual egg weight of early maturing pullets is less than that of the late maturing pullets. It would seem, then, that if birds mature too early, it may result in small body size and small egg size. But very little experimental evidence has been produced to show whether body size or egg size is permanently retarded by early maturity.

Marble and Hall (6) have found in breeding for egg production in high-line and low-line Leghorns a very interesting relation between the first, or pullet, year average body weight and the number of days to sexual maturity. They present curvilinear trends showing the increase in body weight from the years 1908 to 1927 for birds of the high-lines and from the

[2] Symbols used throughout the text: B = Brahma, L = Leghorn, B x L = Brahma male mated with Leghorn female, etc. In all cases the male parent is indicated first.

years 1913 to 1927 for birds of the low-lines. Curvilinear trends are also shown for the number of days to sexual maturity for both the high and low lines. There has been, according to their observations, a steady decrease in the number of days to sexual maturity for the high-lines from 1908 to 1927. The low-lines also show a decrease in number of days to sexual maturity, though not so pronounced as that found in the high-lines. Further, both the high-lines for a twenty-year period and the low-lines for a fifteen-year period show an increase in the mean weight of egg laid during the pullet year.

The work of Marble and Hall suggests that the number of days to sexual maturity may be reduced materially without decreasing the ultimate body weight of the bird or its egg weight, if rigid selection is practiced. On the other hand, the apparent acceleration of maturity in high and low lines alike may depend merely upon improved management, particularly feeding.

In animal husbandry it is generally recognized that growth is retarded if animals are bred at too young an age, and in certain cases the animal may be, in consequence, somewhat smaller as an adult. It has been pointed out by Mumford (8), however, that in swine the difference in size at maturity between animals bred at a very young age and those bred at a later stage is insignificant. Reed et al. (10) state that, in Holstein cattle, cows bred to calve at 24 months of age did not develop so well as the animal on the same feed bred to calve at 30 months of age. Withycombe et al. (13) show that Hereford cows producing a calf each year at the ages of two, three, and four years, averaged about 100 lbs. less when five years old than cows which produced calves only at ages three and four years. From the foregoing facts, it is apparent that animals which suckle their young, if bred at too early an age, have their growth delayed or inhibited, but it is not altogether clear that the size ultimately attained will be limited by such early breeding.

Pease (9), while studying the inheritance of weight in a Polish-Flemish cross of rabbits, was able to make certain observations on date of sexual maturity of these two breeds. His results indicate that time of sexual maturity is not affected by sex and probably not by litter size. Pease further concludes that there is a considerable degree of association between maximum adult weight and slow maturity in rabbits, but that this relation is conspicuously absent in many individuals.

Castle (1) crossed a race of large rabbits with a race of small rabbits. Sexual maturity in the small race occurs at approximately 160-180 days. Sexual maturity occurs later in the large race—about 200 to 250 days—and, as Castle states, ''less obviously affects the character of the growth curve.'' The curve for the hybrid females flattens out abruptly at the time of sexual maturity, which comes in this group somewhat later than in the small race but much earlier than in the large race. It is interesting to note that the growth curves of both sexes flatten out at the time of sexual maturity.

The relationship between growth and time of sexual maturity in the domestic fowl has received little attention from poultry investigators, and it seems desirable, therefore, to observe the effect of this factor on the ultimate size of the bird. Birds being oviparous and mammals viviparous, it is possible that time of sexual maturity has not the same significance in both. Yet intense egg production is a heavy drain on the growing bird,

as are gestation and lactation on a mammal, and we might reasonably expect to find similar effects on the mother in both cases.

MATERIALS AND METHODS

Information on the source and nature of the birds employed in this
investigation has been presented in Bulletin 228 of the Rhode Island
Agricultural Experiment Station, together with a description of the experimental methods used. A cross was made between single-comb White
Leghorns and Light Brahmas. Reciprocal F_1 and F_2 generations were
obtained. Individual pedigree records were kept for every bird used in
the experiment. Each chick was weighed at hatching time and thereafter
at intervals of one week during the first three months and at monthly intervals thereafter until maximum weight was attained. The age at first
egg was used as the age at sexual maturity. It was not practical to weigh
each bird exactly on the day of sexual maturity, and in many instances
it was necessary to estimate this weight by interpolation between the last
weight taken prior to laying of the first egg and the first weight taken
subsequently.

The Leghorn is a small breed, the female weighing approximately
1,600 grams and the male 2,000 grams at 10 months of age. The Brahma
is one of the largest breeds of domestic fowl. The Brahma female weighs
approximately 3,200 grams and the male 4,000 grams at 10 months of age.
Brahma individuals are thus just about twice as heavy as Leghorns.

The numbers of parents and crossbreds used in this experiment were
Brahma 61, Leghorn 374, $F_1$332, $F_2$260, and backcross 34.

SEXUAL MATURITY

A graphic presentation of the variation in age at first egg for the
Leghorns, Brahmas, and their F_1 and F_2 reciprocal hybrids is given in
figure 1. The average age at first egg is 200 days for the Leghorns and
for the Brahmas 291 days. The Leghorns show a distribution for age at
sexual maturity from 120 days to 310 days with a principal modal group
from 200 to 210 days, but with a secondary modal group between 170 and
180 days. As shown below, this bimodal condition is probably due to combining data obtained in different seasons or under different environmental
conditions. The Brahmas show a distribution for age at first egg ranging
from 210 to 390 days and may accordingly be classified as a late maturing
breed.

Figure 2 shows the distribution of the Leghorns for the years 1921
to 1926. The mean number of days to first egg varies somewhat from year
to year, but on the whole there is a general decrease following the year
1922. Inasmuch as there was no selection for early maturity, this decrease
may be attributed to environmental differences in which better feeding
methods probably played a part. A recombination of the data excluding
those of 1925 showed that the secondary mode at 180 days in the combined
data is due wholly to the birds reared in 1925. It was not found in the
flocks of the four earlier years or in the 1926 flock.

In general the age at first egg for the reciprocal hybrids, as shown in
figure 1, approaches that of the earlier maturing parent. The average
age at first egg, based on all matings for the years 1923 to 1926, shows a
difference between the reciprocal crosses which is statistically significant.
The female from the cross of Brahma male with Leghorn female mature,
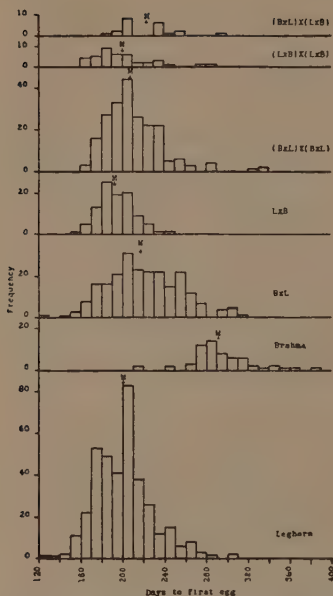
Fig. 1.   Frequency polygons showing
variation in age at first egg for Brahmas,
Leghorns, and their F₁ and F₂ hybrid pro-
genies.
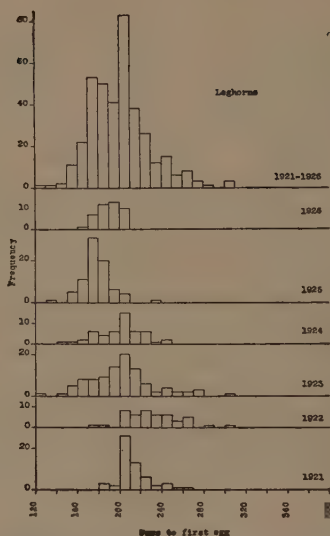
Fig. 2.   Frequency polygons showing
variation in age at first egg for Leghorns
in the years 1921 to 1926.

on the average, at 219 days. The females from the cross of Leghorn male
with Brahma female mature earlier, at 193 days (see table 1).

It would seem that a sex-linked gene or genes determines in part, the
difference between Leghorns and other breeds as regards age at the pro-
duction of the first egg. Figure 3 shows the frequency distribution of
days to sexual maturity for the F₁ reciprocal hybrids year by year from
1923 to 1926 inclusive. The B x L² individuals for the years 1923, 1924,
and 1926 are, on the average, phenotypically later maturing than the in-
dividuals hatched in the year 1925. There is no evidence of the action
of a sex-linked gene in the B x L population for the year 1925, while the
B x L populations for the years 1923, 1924, and 1926, when compared with
the L x B populations, show a mean difference at age of first egg which is
statistically significant. The L x B individuals are nearly all early ma-
turing with but very little variation from year to year. The variation in
days to sexual maturity for the B x L hybrids for the various years, how-
ever, is no greater than that found in the Leghorns for the same years.

For age at first egg the 1925 data, both for the Leghorn and the B x L
birds, are exceptional. The mean age at first egg for the 1925 Leghorns
is nearly 30 days earlier than that of the Leghorns hatched during the
years 1923, 1924, and 1926. Further, the mean age at first egg for the
1925 B x L birds is nearly 40 days earlier than that of the B x L birds
hatched during the years 1923, 1924, and 1926. This exceptionally early

TABLE 1. *Statistics on Brahma and Leghorn Fowl and their F₁ and F₂ hybrids*

	No. of birds	Weight at first egg			Maximum adult weight			Days to first egg			Percentage of adult weight at first egg
		Mean	σ	C.V.	Mean	σ	C.V.	Mean	σ	C.V.	Mean
Leghorn	374	1553 ± 6	185	11.9	1697 ± 7	202	12.0	200 ± 1	27	13.6	91
Brahma	61	3133 ± 24	382	12.2	3190 ± 32	375	11.8	291 ± 3	29	10.2	98
B x L	233	2179 ± 12	278	12.8	2332 ± 12	272	11.7	219 ± 2	34	15.8	93
L x B	99	2200 ± 18	273	12.4	2445 ± 22	321	13.2	193 ± 1	16	8.5	90
(BxL) x (BxL)	194	2275 ± 16	339	14.9	2521 ± 19	400	15.9	208 ± 1	28	13.6	90
(LxB) x (LxB)	40	2324 ± 30	284	12.2	2615 ± 37	351	13.4	200 ± 3	28	14.1	89
(BxL) x (LxB)	26	2262 ± 45	341	15.1	2508 ± 43	326	13.0	223 ± 3	25	11.5	90
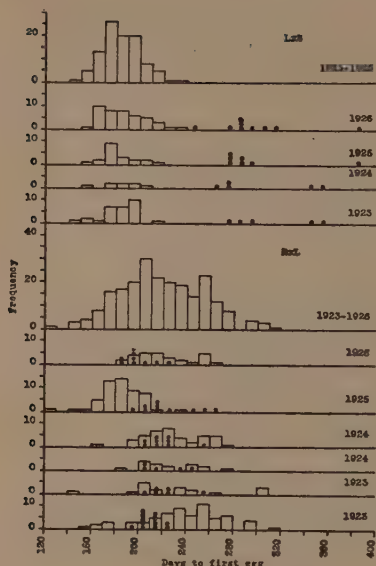
Fig. 3. Large dots show the age at first egg of the 41 Leghorn and 25 Brahma females of the P_1 generation. The polygons show the variation in age at first egg of their F_1 hybrid daughters in the years indicated. The combined data for the F_1 daughters in the years 1923-1926 are also shown.

maturity of the birds hatched in the year 1925 may reasonably be attributed to better environmental conditions.

The F_2 females from the cross B x L matured at 208 days, and the F_2 females from the cross L x B matured at 200 days, while the F_2 females from the cross of (BxL) x (LxB) matured at 223 days. The differences between the variability of the F_1 and F_2 hybrids are not statistically significant.

There is no clear evidence of the action of a sex-linked gene in any of the F_2 samples. It may also be pointed out that the action of a dominant autosomal gene, as proposed by Hays (3), is not evident in the F_2 samples. For if one dominant autosomal gene were responsible for the difference between the late maturing Brahma and the early maturing Leghorn, then the reciprocal hybrids would be all early maturing, and the F_2 samples would show a bimodal distribution, which is not the case.

It has been previously pointed out that for the Leghorns the number of days to first egg ranges from 120 to 310 days. It is essential to establish, if possible, the genetic constitution of those Leghorns which, phenotypically, are early maturing, and also of those which are late maturing. This comparison is obtained by mating each group to a Brahma male. To this end six matings were studied involving six different Brahma males and 41 Leghorn females. Figure 3 shows the variation in age at first egg of these 41 Leghorn females and also of their F_1 daughters. More than half of the 41 Leghorn females matured later than 215 days (the age arbitrarily chosen by Hays as the division between early and late maturing birds). It is possible that some of these late maturing Leghorn females were delayed in laying their first egg because of adverse environmental conditions. However, they were not all hatched in the same year, and it is not probable that the environment was entirely responsible for their late maturity.

By applying Fisher's method of analysis of variance, it is possible to estimate whether the progeny from late maturing Leghorns differs significantly from the progeny of early maturing Leghorns, when both groups are mated to the same late maturing Brahma male, (see table 2.) There is no significant difference in days to sexual maturity between the progenies within any one of these matings. The progenies of late maturing Leghorns do not differ significantly from the progenies of early maturing Leghorns, when both groups are mated to the same late maturing Brahma

TABLE 2. *Analysis of variance in age at first egg among the progeny of various males, each mated to several females*

	F₁1923 (♂ B1R)			F₁1923 (♂ B2C)			F₁1924 (♂ B11B)		
	D/F	Sum of squares	Mean square	D/F	Sum of squares	Mean square	D/F	Sum of squares	Mean square
Between progeny of different hens	6	9,946	1,657	4	2,024	506	3	3,454	1,151
Within progeny of the same hen	58	65,191	1,124	13	26,015	2,099	12	2,958	247
Total	64	75,137	1,174	17	28,039	1,649	15	6,412	427

	F₁1924 (♂ B1IV)			F₁1925 (♂ B12F)			F₁1926 (♂ B34C)		
	D/F	Sum of squares	Mean square	D/F	Sum of squares	Mean square	D/F	Sum of squares	Mean square
Between progeny of different hens	5	1,598	320	9	2,300	256	8	8,681	1,085
Within progeny of the same hen	35	23,670	676	46	14,470	315	19	8,300	437
Total	40	25,268	632	55	16,770	305	27	16,982	628

	F₂1925 (♂ G24C)			F₂1925 (♂ G42B)			F₂1926 (♂ G32G)		
	D/F	Sum of squares	Mean square	D/F	Sum of squares	Mean square	D/F	Sum of squares	Mean square
Between progeny of different hens	7	3,293	470	10	11,740	1,174	6	8,819	1,469
Within progeny of the same hen	52	2,479	477	76	53,620	706	25	33,626	1,345
Total	59	28,079	476	86	65,360	760	31	42,445	1,369
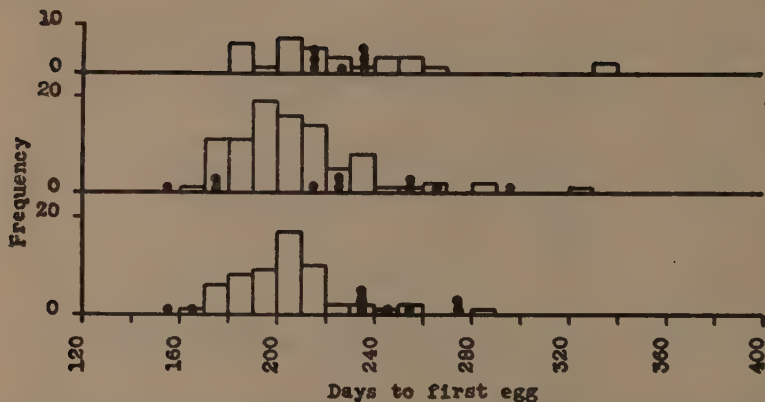
Fig. 4. Large dots show the age at first egg of the F₁ mothers; the frequency poly-gons show the variation in age at first egg of their F₂ daughters for each of the three F₁ matings.

male. The hens in each mating seem not to differ genetically among themselves with respect to sexual maturity.

Of still further interest is the fact that the three F_1 B x L matings give results similar to those found in the P_1 matings and there is no significant difference in days to sexual maturity between the progenies within any one of these F_1 matings. (see table 2). Figure 4 shows the variation in number of days to first egg for three different matings of F_1 females and for their F_2 daughters. Over half of these F_1 females matured later than 215 days. However, we find no significant difference between the F_2 progeny from early maturing and from late maturing F_1 parents, when mated to the same male, as shown in table 2. Apparently these F_1 females are genetically alike with respect to sexual maturity.

The hypothesis advanced by Hays postulates that early maturity depends upon two pairs of dominant genes, one of which is sex-linked. Presence of either of these genes will result in early maturity,—that is, the birds will lay prior to age 215 days. A cumulative effect for these two genes is suggested as possible. If the assumption is made that the Brahma is genetically late maturing, because it has neither the sex-linked gene E nor the autosomal gene E', and if the Leghorn is assumed to be early maturing, because it has both of these genes, then with complete dominance the reciprocal hybrids from this cross should be all early maturing, laying their first egg prior to 215 days. But we observe, in figure 1, that the reciprocal hybrids are not all early maturing. In fact, the hybrids from the cross of Brahma male with Leghorn female are over 50 per cent late maturing. It is true that hybrids from the cross of Leghorn male with Brahma female are, for the most part, early maturing. The difference in number of days to first egg between the reciprocal hybrids suggests, indeed, the action of a sex-linked gene. The evidence is in harmony with this idea, except the result for the B x L hybrids in the year 1925. The fact that the B x L hybrids are later maturing than the L x B hybrids, but not so late maturing as the Brahma breed, suggests an effect of the
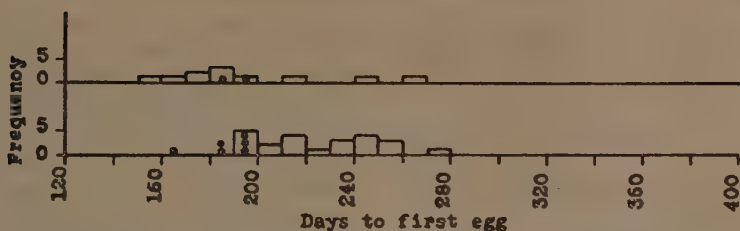
Fig. 5. Large dots show the age at first egg of 2 Leghorn and 6 F_1 female parents; the frequency polygons show the variation in age at first egg of their reciprocal backcross daughters.

assumed sex-linked gene E cumulative with the effects of other genes for early maturity, which may be autosomal.

A critical test of the applicability of Hays' hypothesis to this cross is offered in two backcross matings. If we assume the Leghorn, which is early maturing, to have a genetic formula for the male $(E)(E)E'E'$ and for the female $(E)(—)E'E'$, and if we assume the Brahma male to have the genetic formula $(e)(e)e'e'$ and the female $(e)(—)e'e'$, then we should expect very definite results when these two breeds are crossed together. The F_1 reciprocals should all be early maturing, laying their first egg prior to 215 days. When an F_1 male from the cross of Brahma male with Leghorn female, having the genetic formula $(E)(e)E'e'$, is mated with Leghorn females having the genetic formula $(E)(—)E'E'$, then the expectation is that all the backcross progeny will be early maturing. All but three of the eleven individuals were indeed early maturing. If, now, we backcross to a Leghorn male the F_1 females from a cross of Brahma male with Leghorn females, the expectation is that these backcross progeny will also be early maturing. But, referring to figure 5, we observe that over two-thirds of them are actually late maturing.

The results obtained in this cross between Brahma and Leghorn are not in agreement with the hypothesis of Hays, that two pairs of dominant genes are responsible for early maturity. There is some F_1 evidence of the action of a sex-linked gene for early maturity, but beyond that the hypothesis is not verified. We have observed also that certain individuals in the Leghorn breed are phenotypically late maturing, while others are early maturing. However, when we mate these early or late maturing birds to the same late maturing Brahma, we obtain no significant difference in age at first egg for the pullets produced by the two classes. It is quite evident that, for the birds used in this cross, age at first egg is not a reliable criterion to use in classifying individuals as genetically early or late maturing. Accordingly, the Hays hypothesis is incapable of proof or disproof from these experimental data.

THE RELATION OF GROWTH TO SEXUAL MATURITY

It is evident that the Leghorns used in this study as a group mature considerably earlier than the Brahmas, as is generally conceded by poultry breeders for these breeds. However, poultry breeders will also agree that certain strains of Brahmas attain sexual maturity earlier than other strains, but unfortunately there is no experimental evidence available to substantiate this belief. Further, there is no evidence to show that the average
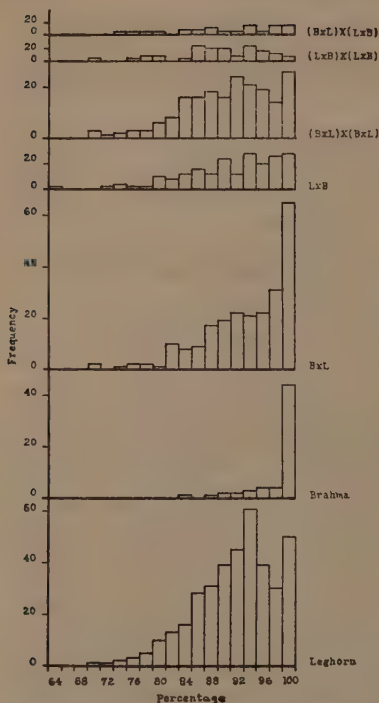
Fig. 6. Frequency polygons showing the variation in percentage of adult weight attained at age of first egg by Brahmas, Leghorns, and their F₁ and F₂ hybrid progeny.

mature weight of early maturing Brahmas is less than that of late maturing Brahmas. Little or no information is available concerning the effect of early maturity on the maximum adult weight of the individual. It is important to know whether early sexual maturity acts as an inhibitor on growth. Also, if sexual maturity is inherited separately from adult size, then it should be possible to produce a strain of early maturing and a strain of late maturing birds that average the same in maximum adult weight.

The percentage of adult weight attained at age of first egg is shown in figure 6 for the Brahmas, Leghorns, and for their F_1 and F_2 hybrid offspring. Here we observe that the Leghorns attained an average of 91 per cent o ftheir adult weight at age of first egg, while the Brahmas attained 98 per cent (see table 1). The reciprocal crossbreds all resemble the Leghorn parent in that they produce the first egg before attaining full growth. The B x L hybrids attained 93 per cent of their adult weight, while the L x B hybrids attained 90 per cent of their adult weight when the first egg is produced. The F_2 groups are also like the smaller race, having attained approximately 90 per cent of their adult weight at age of first egg.

The percentage of adult body weight at first egg for all groups ranged from 63 to 100 per cent. It may be noted that the grouping of these data is skewed to the right.

It has been pointed out previously Waters (12) in this same Brahma and Leghorn cross that mature size is dependent upon two factors: (1) the rate at which growth takes place and (2) the duration of growth. The practical termination of growth comes at ten months of age for both the breeds and for their hybrids. The initial hatching weight is substantially the same in all groups, and the duration of growth is the same. It follows, therefore, that the differential genetic factors which influence adult weight do so through their effects on growth rate.

The question now is whether genes for sexual maturity influence the adult weight of the individual through their effects on the growth rate. Regardless of the number and nature of the genes for sexual maturity, this phenomenon is limited in its expression. A bird can not be sexually mature before a certain percentage of its body weight has been attained,

and the lower limit has been es-
tablished in this cross at about 63
per cent (see figure 6). No sig-
nificant correlation exists between
the number of days to sexual ma-
turity and maximum adult weight
in the Brahmas and Leghorns or
in the F_1 and F_2 hybrids. This
fact would indicate that genes for
sexual maturity may, to some ex-
tent, be independent of genes in-
fluencing adult body weight. Never-
theless, we must also observe the
fact that early sexual maturity is
in general associated with small
body size; for example, the early
maturing Leghorn female is small,
w e i g h i n g approximately 1,600
grams at adult weight, while the
late maturing Brahma is large,
w e i g h i n g approximately 3,200
grams at adult weight. Bu the
Brahma does not begin to produce
eggs until it is practically full
grown, and its production is low
thereafter. Late maturity may
therefore be, in the case of the
Brahma, only one aspect of general
low productive capacity. However,
the F_1 and F_2 hybrid offspring re-
sulting from a cross of these two

Fig. 7. Average growth curves from the
fourth to the tenth month for Brahmas,
Leghorns, and their F_1 and F_2 hybrid pro-
geny. The average number of days to
first egg is marked on each curve by a
large dot.

breeds are comparatively early maturing, and the average adult body weight
is intermediate, although there is an increase in the variability of adult
body weight Waters (12) for the F_2 hybrids over both the parent races and
the F_1 hybrids at ten wonths of age.

The relationship of sexual maturity to growth is clearly expressed in
figure 7, representing the average growth curves of the Brahma, Leghorn,
and their hybrid offspring. The average number of days to first egg is
marked on these curves by a large dot. The fact should be emphasized
that there is a decided flattening of the growth curves after the advent
of sexual maturity.

Figure 8 shows the average growth curves of F_1 and F_2 female popu-
lations separated into three groups (small, intermediate, and large) on
the basis of their 10 months weight as below:

Small	under 2,100 grams
Intermediate	between 2,100 and 2,700 grams
Large	over 2,700 grams

In general, the F_1 and F_2 small, intermediate, and large individuals
are early maturing like the Leghorn breed, regardless of their maximum
adult weight. The growth curves for the large F_1 and F_2 individuals do
not flatten after sexual maturity. Instead, the curves continue to rise for
approximately three months, while the average curves previously presented

Fig. 8. Average growth curves from the fourth to tenth month of age for F_1 and F_2 females separated into three groups, each within weight limits as follows: *large*, above 2,700 grams; *intermediate*, between 2,100 and 2,700 grams; *small* below 2,100 grams. The number of individuals in each group is as follows:

	F_1	F_2
Large	53	78
Intermediate	206	153
Small	73	29

The average number of days to first egg is marked on each curve by a large dot.
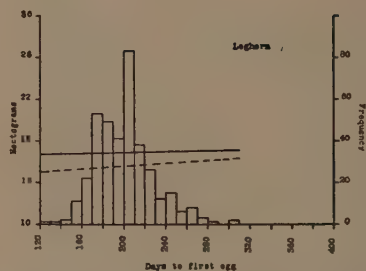
Fig. 9. Frequency polygons showing variation in age at first egg for the Leghorns, together with a broken line showing the general trend of the average body weight of these individuals at first egg and a solid line showing their ultimate average body weight.

for all groups in figure 7 show a flattening after the advent of sexual maturity.

A study of these curves leaves little doubt that genes for early maturity are, to some extent, inherited independently of genes influencing adult body size. For we find that large F_1 and F_2 individuals having an adult weight above 2,700 grams and averaging approximately 2,825 grams for the F_1 and 3,000 grams for the F_2, mature nearly as early as Leghorns which average only 1,600 grams in adult weight. Further, the F_1 large individuals attain an average of 86 per cent and the F_2 large individuals an average of 85 per cent of their adult weight at the production of the first egg. It has been demonstrated by Waters (12) that many of these large F_2 segregates are genetically like the Brahma in weight; nevertheless, they are early maturing like the small-sized Leghorn.

These results again emphasize the complex genetic nature of early maturity and its relationship to growth. In general, the small-sized birds mature earlier than the large-sized birds, but there are many exceptions. It has also been shown previously that there is no significant correlation between the maximum adult weight of the bird and days to first egg.

Graham (2) has demonstrated clearly with Rhode Island Reds that
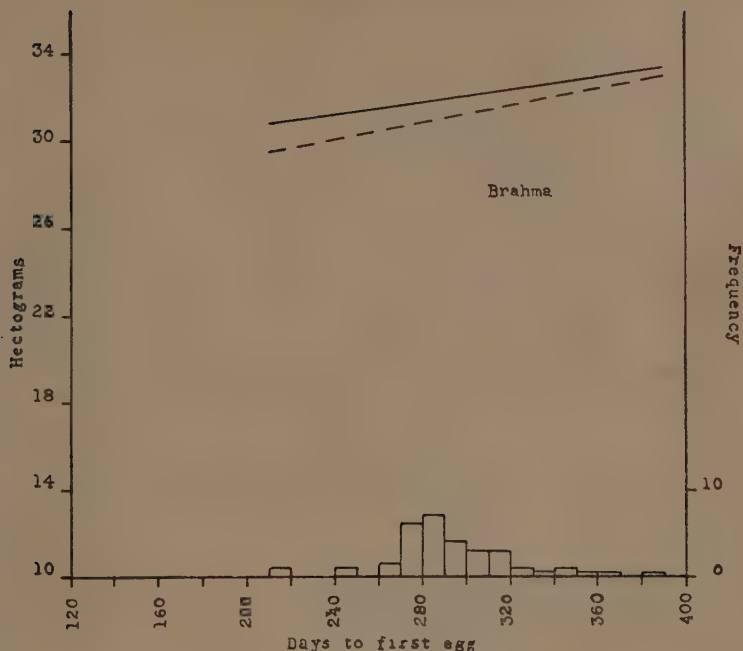
Fig. 10. Brahmas (For explanation see figure 9)

the fewer the number of days to first egg, the lower the body weight of the bird at sexual maturity. The significance of these observations should not be overemphasized, for naturally the earlier the bird commences to lay, the smaller the size of the bird, where as the late maturing bird has had a longer period in which to increase its body size. If, however, the earlier maturing bird fails to attain a maximum body weight equal to that of the late maturing bird, then an important fact has been established The material presented in figures 9-15 affords an opportunity to test this relationship.

Figure 9 shows the frequency distribution of days to first egg for the Leghorns together with a broken line showing the trend of the average body weight of these individuals at first egg and a solid line showing their ultimate average body weight. The age at first egg for the Leghorns ranges from 120 to 310 days. The broken line clearly shows that the early maturing birds are smaller at date of first egg than the late maturing birds. Graham (2) and Hays (4) demonstrate that this is also true for Rhode Island Reds. The solid line shows that the *ultimate* body weight of these early maturing birds is less than that of the late maturing birds, but this difference is not statistically significant.

Figure 10 presents the situation for the Brahma. In this case the age at first egg ranges from 210 to 390 days, with a mean of 291 days. The number of days to maximum adult weight ranges from 270 to 390 days
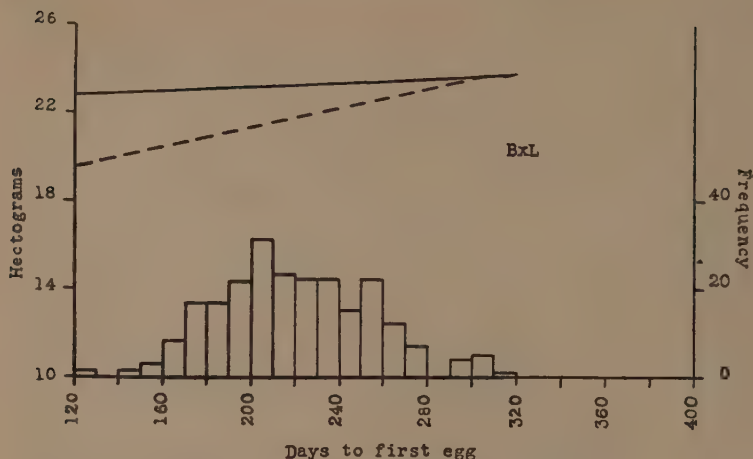
Fig. 11. F₁, B x L (For explanation see figure 9)
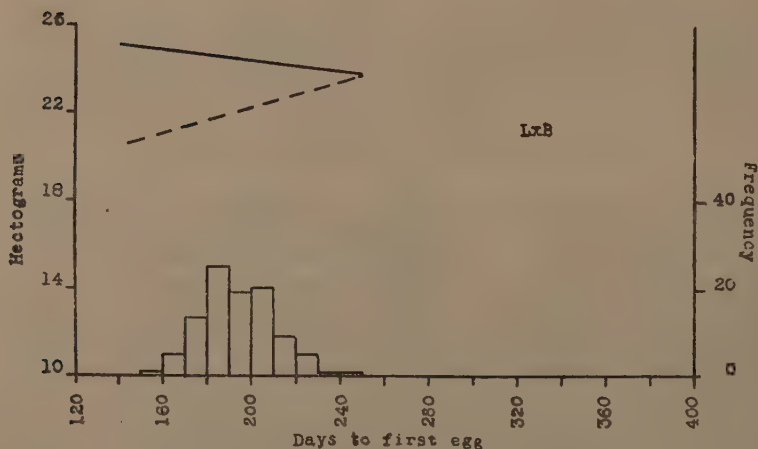
Fig. 12. F₁, L x B (For explanation see figure 9)

for these same birds, with a mean of 309 days. Thus we observe that, as a group, these Brahmas did not mature sexually until nearly maximum adult weight was attained. Therefore, it is to be expected that the regression line for age at first egg will be similar to the one for maximum adult weight.

Figures 11 and 12 show the frequency distribution and trend lines for the F₁ reciprocal hybrids. Here we find a condition similar to that found in the Leghorns. It is true that the early maturing L x B individuals
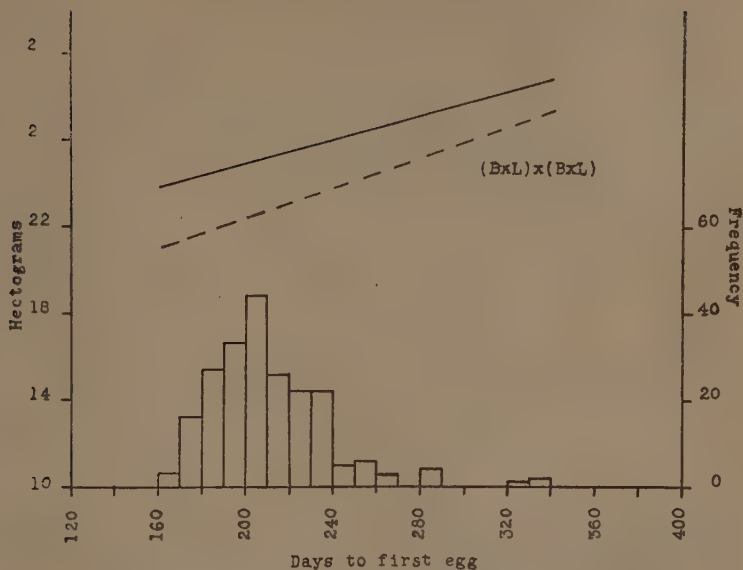
Fig. 13.   F₂, (BxL) x (BxL) (For explanation see figure 9)
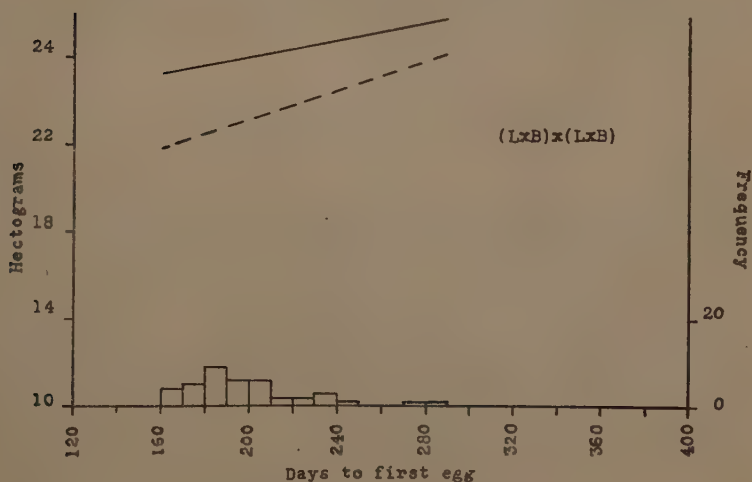
Fig. 14.   F₂, (LxB) x LxB) (For explanation see figure 9)

do attain a slightly higher maximum body weight than the late maturing individuals but this difference is not statistically significant.

In Figures 13, 14 and 15 we find the same general situation for the
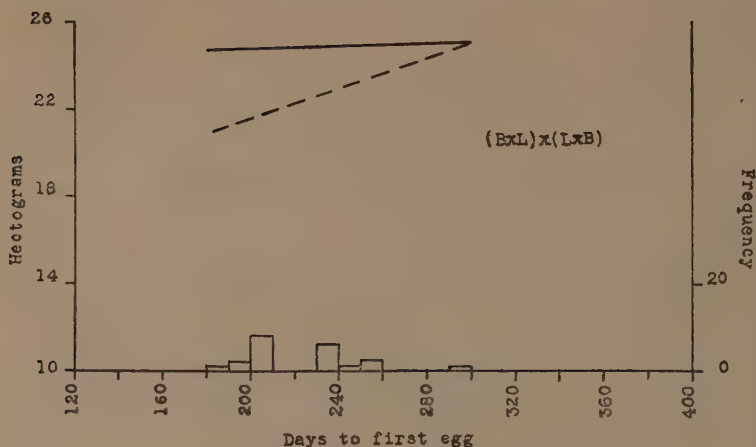
Fig. 15. F₂, (BxL) x (LxB) (For explanation see figure 9)

F$_2$ populations (BxL) x (BxL), (LxB) (LxB) and (BxL) x (LxB). In this case the early maturing females weighed less than the late maturing females at maximum adult weight but again this difference is not statistically significant.

It is evident, from the material presented, that the ultimate body weight is not affected by sexual maturity in the Leghorns, Brahmas, F$_1$ reciprocals, and the F$_2$ generation.

SUMMARY

1. A study has been made of growth and sexual maturity in the Light Brahma and single comb White Leghorn breeds of fowls and in their hybrids.

2. The average age at first egg (or sexual maturity) is 200 days for the Leghorn and 291 days for the Brahma. The Leghorn females range from 120 days to 310 days and the Brahmas from 210 to 390 days.

3. The mean age at first egg for the reciprocal hybrids approaches that of the earlier maturing (Leghorn) parent.

4. The average age at first egg shows, for these reciprocal hybrids, for the years 1923, 1924, and 1926, a difference which is statistically significant. There is no significant difference for the year 1925, but the environment for 1925 was unusually favorable to early maturity. There is accordingly some evidence of the action of a dominant sex-linked gene for early maturity.

5. When early and late maturing individuals from the same flock of Leghorns are mated with the same late maturing Brahma male, we find no significant difference for age at first egg between the daughters of the two groups. This shows that the late maturing Leghorns were late for environmental reasons, not for genetic reasons.

6. For the birds used in this cross, the number of days to first egg is not a reliable criterion to use in genetically classifying individuals as early or late maturing.

7. The results obtained justify the conclusion that the inheritance of sexual maturity is of a very complex nature.

8. A study of the growth curves emphasizes the complex relationship of sexual maturity to growth and leaves little doubt that genes for sexual maturity are to some extent independent of genes influencing adult body size.

9. The correlation between the maximum adult weight of the bird and days to sexual maturity is not statistically significant.

10. The ultimate body weight is not affected by sexual maturity in the Leghorn, Brahma, F_1 reciprocals and the F_2 populations.

ACKNOWLEDGMENT

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SWEET CORN—ITS ORIGIN AND IMPORTANCE AS AN INDIAN FOOD PLANT IN THE UNITED STATES[1]

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The fact that field corn was widely grown in North America previous to the invasion of the white man is well established. Many students of the maize plant also hold the same to be true of sweet corn. Kempton (4) states, "The common forms of maize known to us, sweet, pop, and field or horse corn, were all in existence and widely distributed when Columbus landed." In the writings of Sturtevant and others, similar statements are found. The writer has recently been afforded the opportunity of studying the archeological collections of maize in a number of the leading museums of this country and the findings of this survey lead us to call in question the above conclusions regarding sweet corn as an Indian food plant. There are two important sources of evidence bearing upon this question; namely, archeological recoveries and early literature.

EARLY LITERATURE—SUSQUEHANNAH OR PAPOON CORN

Numerous references to the fact that sweet corn was an Indian food plant are based upon Sturtevant's (6) statement regarding the Susquehannah Indian corn, which he states was "the first sweet corn cultivated in America—and it was secured from the Indians in 1779." Sturtevant refers to this same variety in his notes (7) as Papoon corn.

The basis for his conclusion that sweet corn was an Indian food plant rests upon an article in the New England Farmer (5), written in 1822 by one who assumes the nom de plume of "Plymotheus." As to who Plymotheus was, or what his authority was for the statement regarding the identity of a plant introduced 43 years before, is not indicated. The name assumed rather suggests that he was a resident of Plymouth, Mass. A footnote by the editor refers to General Sullivan's Expedition and Bement (1) states that "sweet corn was introduced into Massachusetts in 1779 by Capt. Richard Bagnell of Plymouth." Bagnell was a member of Sullivan's Expedition, and the Journals of the Military Expedition of General Sullivan contain repeated references to fields of corn and in one it is stated that "a quantity of corn and other vegetables were destroyed." The association with the term "other vegetables" clearly signifies that the corn referred to was used for human food. The fact must be borne in mind, however, that field corn was widely used by the Indians for "roasting ears," and is so used by the white as well even to this day. The variety Early Adams, for example, which is still widely grown as a garden corn, is a type of field corn, not sweet corn (1). In fact, there is evidence to the effect that sweet corn was not prized by the Indians for green corn. Will (8), who

regards sweet corn as an Indian food plant, states, however, that the "Upper Missouri Indians rarely picked the true sweet corn green" and notes that the Papago Indians told him the same. The history of Susquehannah or Papoon corn can scarcely be accepted as other than tradition, the accuracy of which requires verification from other sources (1).

There is also evidence that sweet corn is not especially prized by the Indians as a food plant. In the early months of 1934 the writer traversed the interior of Mexico from the Rio Grande to the Yucatan border. In most of the states are to be found numerous interior villages in which the manners and customs of the people are today much as they were before the days of Cortez. In these villages one finds maize, in some form, as an important article of diet in every household. On the market seed of numerous varieties, usually based upon color distinctions, are offered. However, they were always field corn. As far as we were able to observe in the entire journey across the Republic from north to south, we were unable to secure a single specimen of sweet corn. Inquiry as to seed for "roasting or green corn" brought forth the unvarying reply, as interpreted, "This is what we use," indicating field corn. On market day, in the great Saturday market of Oxoaca, which is regarded as one of the largest typically Indian marts of the Republic, we had the same experience. Here maize, chilles and frejolies hold forth in all their glory, but not a single specimen of sweet corn was offered. Through a skilled interpreter we made repeated requests for seed for "green corn or roasting corn," and invariably field corn was offered. The numerous dialects gather here from all directions, many of them coming from distant points, representing several days' journey afoot. So far as we could learn, none of them knew of sweet corn as a plant different from field corn. Prof. C. Conzatti, author of "Flora Sinoptica Mexicana," who is widely versed in the botany of Mexico, informs me that to the best of his knowledge the aborigines (Indians) do not distinguish between field corn and sweet corn and that field corn is used for "roasting ears." Hotel keepers and vendors gave me the same information. Such a survey can be regarded as only cursory in character, but at least in the important maize regions of the Republic sweet corn is still an unknown plant.

It can scarcely be said that this plant does not exist in some of the innumerable valleys with such widely varying soil and climate. Certainly at the seat of a civilization based upon a maize culture, sweet corn mutations may even occur more frequently than elsewhere. If so, they were evidently not sufficiently prized to justify the necessary care for their propagation, and there seems warrant for the conclusion that sweet corn was not a widely cultivated nor important food plant of the aborigines of the region in which the maize plant probably originated.

The first specific reference to sweet corn in American literature which we have been able to find is contained in the letters of Timothy Dwight. During his presidency of Yale College[2] he made numerous journeys, a report of which he gave in his letters. In his second letter he notes that "maize of the kind called sweet corn is the most delicious vegetable, while in the milk stage, of any known in this country. At New Haven the sweet corn may be had in full perfection for the table by successive plantings from the middle of July to the middle of November. I commonly

[2] Now Yale University.

plant it at 12 different periods in the season.'' He refers to ''maize as palatable, wholesome and capable of being used agreeably in more modes of cookery than any other grain.'' Although he was not a botanist, Dwight's notes on the native flora, and so forth, give evidence of the fact that he was a keen observer and posesessed a trained mind.

The Proceedings of the Massachusetts Horticultural Society afford important evidence regarding the origin of sweet corn. It was the custom of this society to make an annual display of fruits and vegetables, particularly of new varieties, and its yearly proceeding report in detail the varieties upon which repmiums were offered and awards made. In the society's premium list for 1838 for the first time an award is offered for ''Indian corn for boiling.'' There were no entries and the item was dropped from the list. The list for 1846 does not include corn, but an award was made to one named Macondry for *''field corn''* and to Williams for ''12 best and earliest *sweet corn.*'' The fact will be noted that for the first 17 annual exhibits of the society, sweet corn is conspicuously absent. The shows were held in Boston, the most important market center of the New England states, and the fact that the first premiums offered were for ''field corn for boiling'' is not without significance.

The Hovey Magazine of Horticulture, established in 1835, constitutes another important source of early horticultural history. Each year the editor gave a review of ''new and recently introduced vegetables worthy of general cultivation.'' Innumerable varieties of peas and other vegetables are passed in review, but in the first 15 years of this record not a single variety of sweet corn is listed. In 1850 Old Colony sweet corn made its appearance and to Editor Hovey it evidently tasted good as compared with ''Indian corn for boiling,'' for he comments that ''when boiled it is nothing but cream and sugar.'' The year 1850 marks the beginning of an important era in sweet corn development and within the next decade a number of varieties appeared, some of which, Stowell's Evergreen for example, are leading sorts to this day.

Thorburn's Seed Catalogue of 1828 lists ''sugar or sweet corn'' but offers no named varieties, and up to this time we find no named varieties in the literature. Sturtevant, in discussing the history of field corn, calls attention to the fact that ''many varieties are always an evidence of antiquity of culture.'' If the converse of this proposition is equally true, then the absence of multifarious forms of sweet corn may be regarded as evidence of its youthfulness.

In brief, a review of the literature points to the conclusion that sweet corn was not a pre-Columbian food plant of the North American Indian, but rather that it is of comparatively recent introduction.

ARCHEOLOGICAL EVIDENCE

The comment of De Candolle that ''the certainty as to the origin of maize will come rather from archeological discoveries'' applies with equal force to sweet corn.

Excellent archeological collections of maize are found in a number of the leading museums of the United States. The writer has been privileged to study such collections in the Field Museum, the Smithsonian Institution, the Museum of the South west and has by correspondence secured reports as to their maize collections from other leading institutions. In these collections excellent specimens of field corn are to be found representing

the dent, flint and flour types and of various colors and forms. In this survey we were quite surprised to find that sweet corn was conspicuously absent, with a single exception to which we shall refer presently. This is hardly what one would expect if sweet corn were in existence and widely distributed in pre-Columbian times, as suggested by Kempton and others.

The specimen referred to is found in the American Museum of Natural History and was collected in the Aztec ruins of New Mexico by Earl H. Morris. "These ruins," states Morris, "were built by the Chaco people during the Mesa Verde phase of Pueblo III," and he estimates that the ear in question was grown between 1200 and 1300 A.D.

The specimen was loaned the writer for determination by the courtesy of curator, Dr. Clark Wissler and is identified as *Zea mays* var. *saccharata*. The wrinkled pericarp, translucent endosperm and character of the starch grain clearly identify it as sweet corn.

The fact that this ear was recovered in the Aztec ruins of the Southwest is significant. "The evidence of archeology, history, ethnology and philology point to central and southern Mexico as the original home of maize," concludes Harshberger (3) who has made a special study of the origin and nativity of corn. If this conclusion is correct and sweet corn was a widely distributed Indian food plant, then it should be liberally represented in the archeological collections of the Southwest. Morris, however, who has made extensive archeological explorations in this region, writes[a] in reference to this Aztec ear, "I recall nothing of similar appearance among the many finds of corn that I have made in the Southwest."

SACRED CORN

The Indians' fondness for striking colors found expression in various color patterns found in corn, such as the "sacred corn" of the Navajos, and the Zuni collection of Cushings. The Cushings collection of the Zunis contained corn of six different colors representing certain mythical figures and the seventh was supposed to represent sweet corn, but Sturtevant (6), who studied the Zuni collection, notes "there was not a sweet corn among them." Sweet varieties of corn are rather dull and lacking in color effects as compared to field corn and would appear to have but little to offer as a color appeal.

The fact may also be noted that linguistic evidence is lacking in support of the theory that sweet corn was an Indian food plant. The tribes, however widely separated, states Harshberger (3), had a common root for that important cereal (maize), thus among the Delawares we find the term "winaminge," the month of August, literally the time of roasting ears. This appelation applies equally well to field corn, a crop which is known to have been used for "roasting ears" by the Indian. So far as we have been able to learn the equivalent of the term sweet corn or sugar corn has no common root among the various tribes.

GENETIC ASPECT

Genetic studies of the corn plant have made an important contribution to the history of its probable evolution and origin. Sturtevant classed sweet corn as a distinct species, *Zea saccharata*. The genetic evidence points to the fact it is a mutant and hence is a botanical variety of field

[a] Morris, Earl H. Letter to author under date of Nov. 20, 1933.

corn rather than a distinct species. Proof of the theory that sweet corn is a mutant of field corn is furnished by the genetic studies of Dr. E. W. Lindstrom,[4] who in 1929 discovered a single sweet corn kernel as a mutant in a series of pedigree cultures of dent corn. Four generations have been tested and crossed with normal sweet corn and all prove the original kernel to have been a true mutant from field corn. Moreover, two other similar cases of such rare mutations are recorded. In field corn there is a normal change from sugar to starch as the ear approaches maturity, whereas in sweet corn only a comparatively small number of starch grains are formed and many of these are imperfect. In other words, sweet corn is field corn in an arrested state of development and is to be regarded as younger than field corn.

Some of the varieties, such as Golden Bantam, are derived from flint corn, and others, the major portion, from the dent corns. The tendency of sweet corn, under the favorable environment of the corn belt, to revert to field-corn type of becoming more starchy or to form ''starch caps'' is well recognized. Sweet corn is inherently a plant of less vigor and stamina than field corn. When planted too early the seed is more likely to decay, and in the autumn it is slower in curing than the latter, and hence more subject to injury from freezing. In view of these facts, sweet corn mutations would be less likely to survive than field corn in the struggle for existence under the rugged environment of Indian agriculture.

A review of early American literature points to the conclusion that sweet corn made its appearance in the United States as a food plant near the beginning of the nineteenth century. A study of maize material in archeological collections of this country would seem to indicate that maize was comparatively rare and hence not an important Indian food plant. The single authentic archeological specimen so far recorded from the United States may be accounted for as a field corn mutant.

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ON THE RATES OF CONTRACTION OF THE ISOLATED HEART AND MALPIGHIAN TUBE OF THE INSECT, PERIPLANETA ORIENTALIS: METHOD

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Although much experimental work has been done upon the insect heart, it has usually involved the intact animal rather than the isolated heart preparation, separated from the influences of nervous or other systems of the organism. It is well known, however, that the surviving insect heart will continue its rhythmic activity for some time when bathed with the proper fluid. Levy (1,2) employed a buffered saline solution in which the isolated hearts of the dipterous larvae, *Phormia regina* and *Calliphora erythrocephala*, remained active for four or five hours usually, but sometimes longer (up to twenty-four hours in one case). Brocher (3) used the isolated hearts of *Dytiscus marginalis* imagos and *Aeschna* larvae for qualitative observations. Koidsumi (4) used the isolated insect heart in a study of critical thermal increments but did not observe heart rate over prolonged periods. Similarly, although the rhythmic activity of the Malpighian tubes has been reported a number of times (5, 6, 7) there is lacking detailed information as to the fluctuation in activity rate when the surviving tissue is observed for prolonged periods of time.

This paper is the description of a method being used by the authors for determining the rates of contraction of the isolated heart and Malpighian tubes of the cockroach, *Periplaneta orientalis*, under controlled experimental conditions of temperature, hydrogen ion concentration, composition of immersion fluid, oxygen supply and rate of renewal of immersion fluid. The immediate objective of these experiments was to determine whether, under these conditions, the rates of heart and Malpighian tube contraction would be sufficiently ''steady'' to permit of their use in determining the effects of various chemical substances on insect muscle activity. The animals used were large nymphs and adults, kept in the laboratory under fairly constant conditions of room temperature and food.

METHOD

The method of isolating the heart used here consists of first inactivating the animal by submersion for a minute or two in water or in the solution in which the dissection is to be made. The legs are severed near the body and the neck is severed as near the head as possible. The body is anchored dorsal side down to a removable wax-impregnated cardboard strip that forms part of the bottom of a rectangular, wax-covered dissecting tray, by two pins thrust through the thin lateral margins of the pronotum. With small scissors an incision is made from the anal extremity to the severed end of the neck, care being taken that the alimentary canal is not cut and that none of its contents is spilled into the hemocoele. The lateral halves of the ventral body wall are carefully separated with the points of pins and are pinned to the wax strip, inner surface uppermost, leaving the entire viscera exposed to view. The severed esophagus

is held with forceps and carefully lifted ventrally and posteriorly and, at the same time, the fat bodies are gradually cut as close as practicable to their body wall attachments. Finally, when the entire alimentary tract, with its attendant fat bodies and Malpighian tubes, is extended posteriorly from the anal end of the body wall, the rectum is pulled posteriorly until the posterior end of the heart is clearly visible; the rectum is pinned in this position, the remainder of the viscera being cut away. These operations leave the entire heart exposed to view on the inside of the dorsal body wall and, when the preparation is carefully made, vigorous contractions can be observed. If the preparation is hurriedly or carelessly made, the heart is apt to show very irregular contractions or no contractions in some or all of its parts; these effects may be due to injury of the delicate pericardium or of the wing muscles of the heart.

The Malpighian tube preparation is the same, except that the alimentary tract is left in position after lateral extension of the ventral body wall and only bits of fat body are removed to facilitate observation of the tubes.

The removable wax strip with attached heart or Malpighian tube preparation is immersed in the saline solution held by the test tube (TT) which is itself immersed in the water of the constant temperature bath held by the glass jar (J), the preparation (P) being vertical in position. Fresh saline from a Mariotte pressure bottle (B₁) is added to the test tube contents by drops from the dropping pipette (D) above and oxygen is supplied by bubbling air or oxygen (A₁) through the fluid in the test tube; the latter serves both to aerate the saline and to make it circulate, the circuit being downward on the preparation side of the wax strip (W) and upward on the other side. The saline level rises because of the added drops, until the excess is drained off through the side arm (SA) of the tube; this occurs periodically. The temperature of the saline and of the bath water is measured by the thermometers (T₁, T₂). The bath water is stirred by motor or by the bubbling through of compressed air (A₂) and is heated and regulated by a heater-thermostat unit (Th) that maintains temperature to about 0.2°C. The preparation is illuminated by a strong beam of light from a low voltage, incandescent lamp (L, not shown), and is observed through a binocular dissecting microscope (M, not shown) mounted horizontally upon an adjustable, rack and pinion support. Contraction rates are obtained by measuring the time required for a given number of complete contractions to occur and then converting to number of contractions per minute. In a given experiment, a single Malpighian tube is selected and its contraction rate measured throughout the entire period of observation.

This method is applicable not only to the study of isolated heart and Malpighian tubes but also to various parts of the gut. During the present observations, the hind-gut has been observed to maintain activity for as long as seven hours and the crop for almost as long. The gizzard, which does not readily continue its activity when isolated (see 8) has been noted to contract for a few minutes. The mid-gut has exhibited little or no activity.

SALINE

The physiological saline used to bathe the preparation is one described by Levy (1) but has been slightly modified by the addition of glucose. It
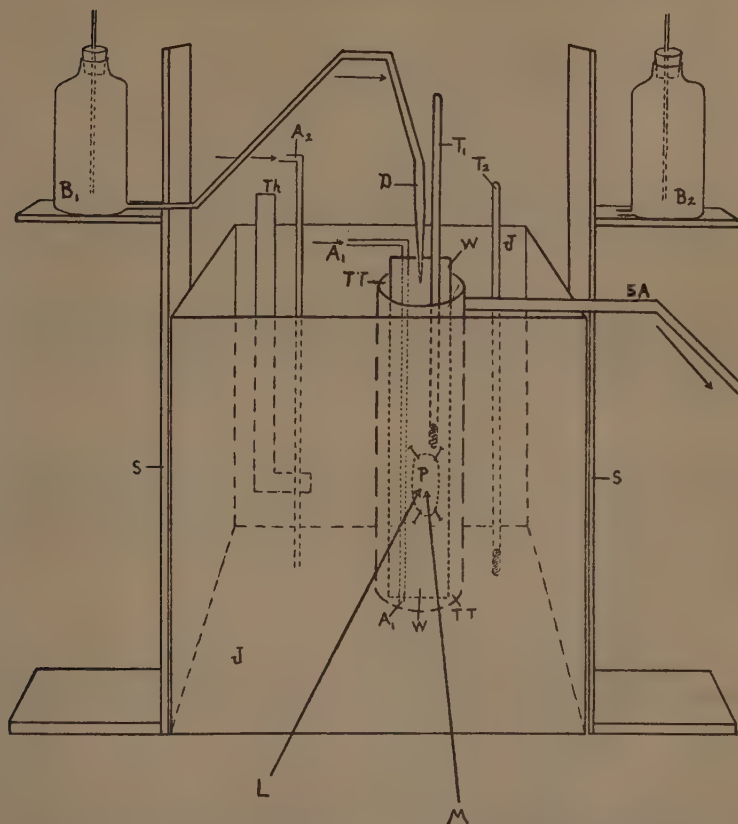
Fig. 1. Set-up used for determining rates of isolated heart and Malpighian tube contraction of the insect, *Periplaneta orientalis*, over prolonged observation periods, under conditions of constant temperature, pH, composition and rate of renewal of physiological saline. For purposes of illustration the relative size of the side arm test tube (TT) and its contents has been exaggerated and the supporting clamps for the various apparatus have been omitted.

A₁, A₂   inlets for compressed air to physiological saline and water bath, respectively.

B₁, B₂   bottles of saline with Mariotte-tube for maintaining constant pressure.

D   dropping pipett from which saline drops fall into test tube.

J   glass side of thermostat jar.

L   low voltage incandescent lamp used to illuminate preparation.

M   position of horizontally arranged dissecting microscope used to observe preparation.

P   heart or Malpighian tube preparation.

SA   side arm for drainage of saline from test tube.

S, S   supports for bottles of saline.

T₁, T₂   thermometers for measuring temperature of saline and water bath, respectively.

TT   side arm test tube containing preparation, etc.

W   wax-impregnated cardboard strip that holds the preparation.
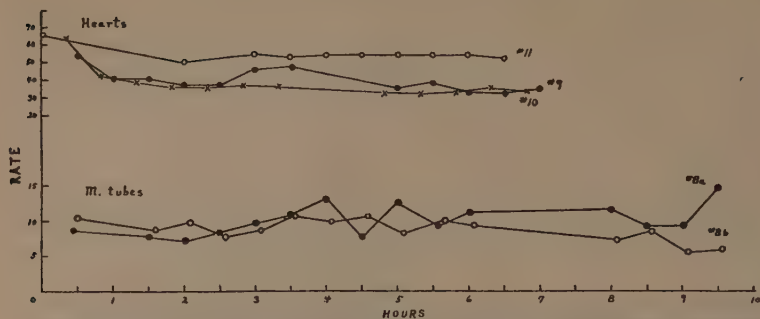
Fig. 2. Contraction rates of isolated hearts and Malpighian tubes of the cockroach, *Periplaneta orientalis*. Rates are expressed as number of contractions per minute. Hours refer to the number of hours from the beginning of the experiment. Curves No. 8a and No. 8b are at 26.5°C.; No. 9 and No. 10 at 25.0°C.; and No. 11 at 23.0°C. All are buffered to approximately pH = 7.5.

is approximately one-eleventh Levy's stock solution but contains 0.1 per cent glucose and is buffered to approximately a pH of 7.5 or 8.0 in different experiments. Its composition is 9.82 gms. NaCl, 0.77 gm. KCl, 0.50 gm. CaCl$_2$, 0.18 gm. NaHCO$_3$, 0.01 gm. NaH$_2$PO$_4$, 1.00 gm. glucose; this is made up to one liter of solution with distilled water and then adjusted to the required pH value.

RESULTS

A number of experiments have been made to determine the change in rate of contraction with time. Typical results with both heart and Malpighian tube preparations are given in figure 2.

DISCUSSION AND CONCLUSIONS

The results obtained indicate that, in general, the rate of heart beat is several times as great as that of the Malpighian tube and that the heart rate may show a relatively rapid decrease during the first hour after isolation,[1] after which it is maintained at an approximately uniform level for a period of at least six or seven hours. The Malpighian tubes have shown a surprisingly constant rate of contraction, even up to 10 hours of observation. The contraction rate of the Malpighian tube shows greater fluctuation than does heart rate but these variations are not so great as to obscure the general constancy of the Malpighian tube activity. It is apparent also that, under these experimental conditions, the rates of heart beat and Malpighian tube contraction are sufficiently "steady" over a sufficiently long time to be used in determining the effects of various dissolved substances upon insect muscle activity. In the present work it has been observed that the duration of Malpighian tube activity is increased by the presence and decreased by the absence of glucose in Levy's solution.

It is suggested that this method may be of use in determining the

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[1] This accords with the report of Levy (1) that the insect hearts he used exhibited a rapid decrease in rate immediately following isolation.

direct action of certain insecticides upon the isolated insect tissue, about which little is at present known.

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THE ALKALINE HYDROLYSIS OF CELLULOSE ACETATE RAYON

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Cellulose acetates as textiles have been hydrolyzed with alkali in the preparation of lower acetates for the spinning bath (7, 15, 21, 35, 37, 45-47, 49, 50, 57, 59, 75, 79-83, 88, 89, 93, 95, 110, 116, and 118), in the preparation of alkali cellulose (105), in the scouring (55, 56, 86, and 87), degumming (54, 74, and 101), and mercerizing (76, 77, 103, and 106) of union textiles containing cellulose acetate rayon, in the dyeing (2, 3, 5, 8, 10, 22-29, 34, 44, 52, 58, 62, 67, 71, 84, 85, 96-98, 102, 104, 107-109, 111, 117, and 119) and stripping (30 and 68) of cellulose acetate rayon, in such special finishing processes as delustering (4, 6, 16, 18, 19, 65, 66, 70, 113-115), crêping (13, 14, 32, 51, and 69), and iron-proofing (12, 17, 20, 36, 40-43, 60-62, 91, 94, 95, and 112), in processes designed to increase the resistance of a fabric of cellulose acetate rayon to wrinkling (92) or to make easier the clear cutting of pile yarns (11 and 48), and in producing decorative fabrics in which the cellulose regenerated is destroyed by carbonization (38 and 39). In most of these cases the cellulose acetate rayons have been three to twenty per cent hydrolyzed at about 70°C. in 0.025N to 0.3N alkali.

Kita, Sakurada, and Nakashima (72) have reported the fifty per cent hydrolysis of cellulose acetate by aqueous sodium hydroxide as a monomolecular reaction and they and others (1, 33, 72, 99, and 100) have used rates of hydrolysis to differentiate cellulose acetates. Haller and Ruperti (63 and 64) have described hydrolyzed cellulose acetate rayon as an unhydrolyzed center within a completely hydrolyzed surface; Colthof, Waterman, and Wolf (34) have described it as made up of intermediary layers of partially hydrolyzed ester within a completely hydrolyzed surface.

The loss of acetyl and loss of weight of a cellulose acetate rayon in fifteen minutes at 60°C. over a range of concentrations of alkali are presented in this paper.

EXPERIMENTAL

A cellulose acetate rayon fabric of plain weave was boiled one hour at constant volume in one hundred times its weight of water, rinsed, dried, and extracted continuously for eighteen hours with anhydrous ether. The fabric prepared in this manner yielded 37.67 per cent of acetyl by Ost's (53, 90) method.

Samples of approximately one gram of the fabric were dried at 105°C. until constant and weighed with tares. Fifty cubic centimeters of a standard solution of sodium hydroxide were pipetted into 300-cc. Erlenmeyer flasks, the flasks were fitted with rubber stoppers, and placed in a water bath regulated at 60 ± 0.1°C. until the contents of the flasks attained the temperature of the bath. A sample of cellulose acetate rayon was added to each flask, the mixture was shaken during fifteen minutes at 60°C., and

TABLE 1. *The effect of alkali on the weight and the acetyl content of cellulose acetate rayon.*
Temperature, 60° C.
Time, 15 minutes

Determination number	Sodium hydroxide normality	Rayon gram	Loss in weight percentage of rayon	Weight of residue percentage of rayon	Weight calculated from loss of acetyl percentage of rayon	Acid required for neutralization of hydrolysate cc. 0.0557 N	Acetyl lost upon hydrolysis gram	Acetyl of residue percentage of rayon	Acetyl of residue percentage of residue
1	0.0210	0.9365	0.3			18.10	0.0018	37.5	
2		0.9375	0.1			18.10	0.0018	37.5	
3		0.9624	0.2			18.10	0.0018	37.5	
Average			0.2	99.8	99.8			37.5	37.6
1	0.0489	0.9174	1.8			37.10	0.0163	35.0	
2		0.9366	1.7			37.43	0.0155	36.0	
3		0.9372	1.9			36.80	0.0170	35.9	
4		0.9441	1.7			36.86	0.0169	35.8	
5		0.9467	1.5			37.50	0.0153	36.0	
Average			1.7	98.3	98.3			35.9	36.5
1	0.0652	0.9522	4.6			39.92	0.0446	33.0	
2		0.9539	4.7			39.23	0.0462	32.8	
3		0.9512	4.7			39.90	0.0446	33.0	
4		0.9506	4.9			38.76	0.0474	32.7	
Average			4.7	95.3	95.3			32.9	34.5
1	0.0965	0.9122	13.0			36.50	0.1201	24.5	
2		0.9342	12.8			36.35	0.1205	24.8	
3		0.9307	13.3			35.10	0.1235	24.4	
Average			13.0	87.0	87.2			24.6	28.2
1	0.1100	0.9397	17.0			32.50	0.1587	20.8	
2		0.9209	15.7			38.12	0.1453	21.9	
3		0.9694	16.3			32.35	0.1591	21.3	
4		0.9416	15.8			36.12	0.1501	21.7	
Average			16.2	83.8	84.0			21.4	25.6

TABLE 1. (Continued)

Determination number	Sodium hydroxide normality	Rayon gram	Loss in weight percentage of rayon	Weight of residue percentage of rayon	Weight calculated from loss of acetyl percentage of rayon	Acid required for neutralization of hydrolysate cc. 0.0557 N	Acetyl lost upon hydrolysis gram	Acetyl of residue percentage of rayon	Acetyl of residue percentage of residue
1	0.1300	0.9341	18.4			44.05	0.1741	19.0	
2		0.9413	18.5			43.03	0.1765	18.9	
3		0.9508	18.6			41.35	0.1806	18.7	
Average			18.5	81.5	81.6			18.9	23.2
1	0.1502	0.9528	22.3			45.26	0.2146	15.1	
2		0.9525	23.5			40.50	0.2261	13.9	
3		0.9784	22.1			43.90	0.2179	15.4	
4		0.9045	20.8			55.23	0.1908	16.6	
5		0.9860				46.93	0.2106	16.3	
Average			22.2	77.8	78.3			15.5	19.9
1	0.1760	0.9076	26.5			54.98	0.2469	10.5	
2		0.9581	26.2			50.98	0.2564	10.9	
3		0.9067	25.9			57.58	0.2406	11.1	
4		0.9589	27.0			47.10	0.2657	10.0	
Average			26.4	73.6	73.6			10.6	14.4
1	0.1957	0.9312	30.4			56.28	0.2861	7.0	
2		0.9508	28.6			60.35	0.2764	8.6	
3		0.9557	29.2			58.15	0.2816	8.2	
4		0.9160	30.4			57.13	0.2841	6.7	
5		0.9474	29.9			56.40	0.2858	7.5	
Average			29.7	70.3	70.6			7.6	10.8
1	0.2202	0.9488	32.5			68.13	0.3104	5.0	
2		0.9628	31.1			71.12	0.3033	6.2	
3		0.9708	30.1			74.95	0.2941	7.4	
Average			31.2	68.8	69.2			6.2	9.0

GRAPH I
EFFECT OF ALKALI ON THE WEIGHT OF CELLULOSE ACETATE RAYON

Temperature 60°C
Time, 15 minutes

GRAPH II
EFFECT OF ALKALI ON THE ACETYL CONTENT OF CELLULOSE ACETATE RAYON

Temperature, 60°C.
Time, 15 minutes.
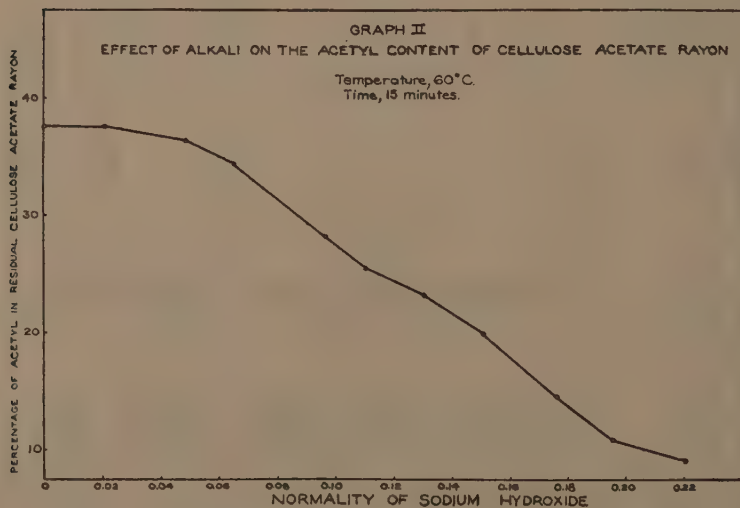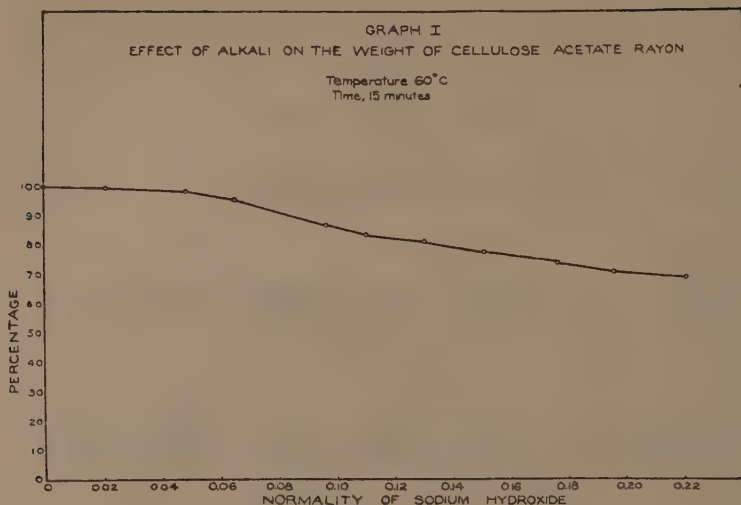
then placed in an iced bath for titration with 0.0557 N hydrochloric acid in the presence of phenolphthaléin. The residual fabric was removed after titration of the hydrolysate, rinsed three times for twenty minutes each by shaking with 200 cc. of water, and dried to constant weight.

The data have been selected from five or more determinations at each concentration of alkali and are presented in table 1 and in graphs I, II, and III.

Acetyl values for the residual fiber corresponding to cellulose diacetate,

34.96, and cellulose monoacetate, 21.08, were obtained upon hydrolysis with sodium hydroxide at 60°C. in fifteen minutes at 0.06 N and 0.142 N. The acetyl values of the fiber between these normalities and those at concentrations g r e a t e r than 0.142 N sodium hydroxide are functions, of the form $y = ax^b$, which plot as straight lines on logarithmic paper (graph III). These data suggest the participation of the entire fiber in the stepwise (78) alkaline hydrolysis of acetylated cellulose.

GRAPH III
EFFECT OF ALKALI ON THE
ACETYL CONTENT OF
CELLULOSE ACETATE RAYON

Temperature, 60° C.
Time, 15 minutes

SUMMARY

1. The alkaline hydrolysis of a fabric of cellulose acetate rayon (37.67 per cent acetyl) in fifteen minutes at 60°C. has been followed by determination of the loss in weight and in acetyl.

2. The decrease in weight has been found to be, within the accuracy of the determinations, that calculated from the loss of acetyl.

3. Acetyl values for the diacetate and the monoacetate have been obtained at 0.06 N and 0.142 N sodium hydroxide. The acetyl value of the residual fiber between these normalities and also that at greater concentrations have been shown to be functions of the alkali concentration of the form $y = ax^b$.
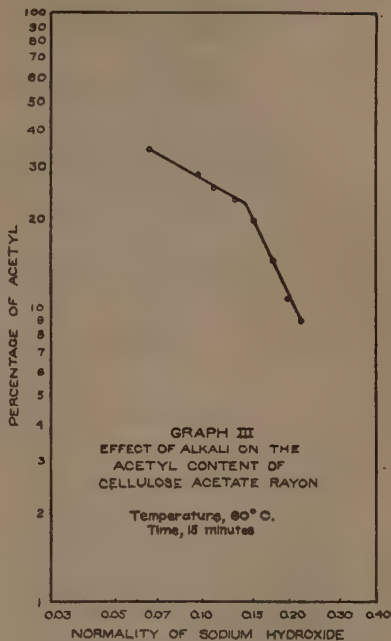
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THE DECOMPOSITION OF STRAW IN THE PRODUCTION OF ARTIFICIAL MANURE[1]

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Many different kinds of organisms are active in the decomposition of plant materials and many intermediate products are formed which are subject to further decomposition. Under certain conditions, however, the decomposition of plant materials may lead to the formation of more or less stable products resistant to further decomposition under those conditions. Certain constituents are readily attacked by a large variety of microorganisms, whereas, other constituents are subject to attack by a relatively small number of microorganisms. The latter constituents are said to be more resistant to decay and under certain conditions they may tend to accumulate. Lignin is a plant constituent not as readily attacked by the common soil microorganisms as some other plant constituents and hence it tends to accumulate in the soil.

In a series of experiments on the production of artificial manure (4) results were obtained which indicated that lignin decomposed rather readily or was altered in such a way that it became soluble in strong acids. The study has been continued and the present paper is a report of the results obtained.

EXPERIMENTAL

MATERIALS AND METHODS

In an experiment on the production of artificial farm manure from oat straw, four ricks, each containing 1,000 pounds of dry oat straw were treated on August 1, according to the outline given in table 1.

TABLE 1. *Outline of treatments*

Compost No.	Treatment
1	1,000 lbs. oat straw + Adco
2	1,000 lbs. oat straw + cyanamid and rock phosphate*
3	1,000 lbs. oat straw + ammonium sulfate, superphosphate and limestone**
4	1,000 lbs. oat straw

*37.5 lbs cyanamid and 37.5 lbs. 200-mesh rock phosphate
**75 lbs. mixture containing:
    45 percent ammonium sulfate
    15 per cent superphosphate (16 per cent)
    40 per cent 100-mesh limestone

Water was added at the rate of 250 gallons per ton of dry straw when the composts were made and no more water was added except that which fell as rain or snow.

The composts were sampled three times the following year and the composts were thrown out of the ricks, reworked completely, then packed back into the ricks after each sampling. The samples were taken on April 2, July 7 and October 16. A sharp spade was used to cut a sample about a foot square from the top to the bottom of the compost. The sample was taken each time near the center of the compost. The samples were air-dried and ground to pass a 70-mesh screen. Nitrogen was determined in all samples by the Kjeldahl-Gunning method. One-gram samples were ignited in an electric muffle furnace at 800°C. for ash determinations. The amount of organic matter soluble in 6 per cent hydrogen peroxide was determined by the method of Robinson and Jones (3). The degree of decomposition of each manure at each sampling was calculated.

TABLE 2. *Analyses of straw and of composts sampled April 2*

Compost No.	Percentage			
	Nitrogen	Soluble in 6% H_2O_2	Ash	Decomposed
Straw*	0.71	15.75	8.55	——
1	2.74	13.91	36.81	23.18
2	1.97	13.72	36.75	22.81
3	2.71	11.43	27.36	16.32
4	2.16	12.13	18.18	15.17

* Sample of straw used in compost.

In addition to the above determinations, the organic carbon, pentosan,[2] cellulose, lignin, hot water-soluble and ether-soluble materials were determined on the samples taken on July 7 and October 16.

The pentosan content was determined by the A.O.A.C. method. Cellulose was determined by the method of Mehta (1). The 72 per cent sulfuric acid method for lignin as modified by Ritter, Seborg and Mitchell (2) was followed. The hot water-soluble material was determined by boiling a one-gram sample in 100 cc. of distilled water 30 minutes under a reflux and determining the solids in an aliquot taken for evaporation. The ether extract was determined similarly in a Bailey-Walker fat extraction apparatus. The organic carbon was determined by the dry combustion method.

RESULTS

Some decomposition had taken place in all composts during the period from August to the following April as is evidenced in the analyses shown in table 2. A considerable increase in the nitrogen content of all manures occurred. The increases in the percentage of ash in all composts indicate considerable decomposition. A superficial examination of the composts indicated a degree of decomposition approximately the same as shown by the data in the table.

The data in table 3 show that the percentage of nitrogen in all composts was lower at the July 7 sampling than at the April 2 sampling. The pentosan content was decreased considerably in all composts below the amount contained in the original straw. The cellulose content of all com-

2 Furfuraldehyde-yielding constituents.

TABLE 3. *Analyses of straw and of composts sampled July 7*

Compost No.	Ether extract	Hot water extract	Soluble in 6% H_2O	Pento-san	Cellu-lose	Lignin	Ash	Decom-posed	Organic carbon	Nitro-gen
Straw	1.15	14.07	15.75	20.99	26.11	19.00	8.55	—	41.81	0.71
1	0.57	10.62	21.22	6.61	9.54	22.78	46.34	39.54	29.49	2.36
2	0.22	7.66	23.32	8.91	11.74	25.16	52.25	48.83	29.75	1.86
3	0.36	10.49	21.92	10.17	12.26	32.41	32.31	32.47	35.86	2.23
4	0.43	13.41	28.58	13.40	17.50	30.74	9.60	33.61	42.89	1.49

TABLE 4. *Analyses of straw and of composts sampled October 16*

Compost No.	Ether extract	Hot water extract	Soluble in 6% H_2O	Pento-san	Cellu-lose	Lignin	Ash	Decom-posed	Organic carbon	Nitro-gen
Straw	1.15	14.07	15.75	20.99	26.11	19.00	8.55	—	41.81	0.71
1	0.26	9.02	27.91	3.72	8.33	23.79	56.43	64.08	23.58	1.56
2	0.21	7.30	23.83	3.20	6.07	19.89	63.64	65.62	18.91	1.36
3	0.56	13.14	24.90	8.86	11.44	27.51	34.40	37.93	32.59	2.21
4	0.39	13.10	21.78	7.17	10.89	31.53	41.03	36.97	22.19	1.72

posts was also decreased to a large extent and the disappearance of cellulose paralleled somewhat the loss of pentosans but to a slightly less extent. The percentage of lignin increased slightly in composts 1 and 2 and to a much greater extent in composts 3 and 4 over that found in the original straw. There was a marked increase in the percentage of ash in all composts except 4. The amount of materials soluble in hot water decreased in all composts but to a much greater extent in compost 2. The percentage of ether-soluble substances was highest in the original straw and lowest in compost 2. The percentage of material soluble in hydrogen peroxide was increased at the July 7 sampling over that of the April 2 sampling. The degree of decomposition as calculated from these data indicates the largest decomposition of straw in compost 2 and the least decomposition in compost 3.

The analyses of the composts at the October 16 sampling are given in table 4.

The nitrogen content of composts 1, 2 and 3 decreased slightly, whereas, it increased in compost 4. The pentosan content was reduced to a small percentage in all composts. The percentage of cellulose in all composts was considerably decreased over that present at the July sampling. The percentage of lignin, though still higher than that of the original straw, was decreased considerably in composts 2 and 3 over that present at the July 7 sampling. The ash content of all manures increased materially during the period from July 7 to October 16. The degree of decomposition was high in composts 1 and 2 and relatively low in composts 3 and 4.

TABLE 5. *Analyses of manures on the basis of original organic matter*

Compost No.	Percentage					
	Sampled July 7			Sampled October 16		
	Pentosan	Cellulose	Lignin	Pentosan	Cellulose	Lignin
Straw	20.99	26.11	19.00	20.99	26.11	19.00
1	1.22	1.76	5.11	0.43	0.97	2.75
2	1.46	1.92	4.15	0.43	0.81	2.71
3	2.68	3.24	8.57	2.15	2.84	6.92
4	10.98	14.34	25.13	1.50	2.27	6.58

The data show a decrease in easily decomposable constituents of the straw and an increase in the ash and H_2O_2-soluble content of the composts as decomposition proceeds. The degree of decomposition correlates fairly well with the disappearance of certain constituents of the straw, such as organic carbon, pentosans and cellulose. Compost 2 was 65.62 per cent decomposed at the October 16 sampling and the lignin content was 19.89 per cent, an increase of 0.89 per cent lignin. These data show that lignin decomposes more slowly than pentosans and cellulose but that the lignin has undergone some decomposition. If the percentage of lignin in the manures could be calculated upon the basis of the original organic matter or straw, the extent of decomposition of the lignin would be apparent. An estimate of the lignin content of the manures based upon the original organic matter by means of the ash and loss on ignition data was made. The results are given in table 5.

The pentosan content of the composts 1, 2 and 3 was reduced to a small percentage at the July 7 sampling, whereas, the untreated straw still contained a large percentage of this constituent. At the October 16 sam-

pling the pentosans had been reduced to a minimum in all composts. The cellulose content of all composts had largely disappeared at the October 16 sampling. The percentage of lignin calculated on the basis of original organic matter was low in all composts at both samplings, except in the case of compost 4 at the July 7 sampling. The low lignin content of all manures at the October 16 sampling shows that lignin has disappeared and at a rather surprisingly rapid rate compared with the disappearance of pentosans and cellulose.

SUMMARY AND CONCLUSIONS

Samples of composted straw were taken at intervals over a period of 15 months. Analyses of the composts at the end of the period showed that the cellulosic and furfuraldehyde-yielding constituents had largely disappeared and that 60 to 90 per cent of the lignin was decomposed. The loss in organic carbon was parallel to the gain in ash constituents. The material soluble in 6 per cent hydrogen peroxide increased slightly and that soluble in hot water and in ether decreased slightly as decomposition proceeded. With favorable environmental conditions these constituents would no doubt have decomposed more rapidly than they did in this experiment.

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THE BUTYL-ACETONIC FERMENTATION IN SUGAR MEDIA[1]

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Donker (1926) and Van der Lek (1930) have studied extensively the butyl-acetone fermentation and have reported good production of 'solvents' from glucose in the presence of either yeast or peptone as the source of nitrogen. In general, the fermentations were more nearly complete with yeast extract.

Robinson (1922) divided the mono-saccharides into two groups on the basis of their dissimilation by *Clostridium acetobutylicum*. The one group, including glucose, fructose and mannose, gave the characteristic acid curve of the butyl-acetonic fermentation, the acidity rising rapidly to a maximum followed by a sharp decline. In the second group of sugars including xylose and galactose, there was little drop in the acidity following the maximum.

Peterson, Fred and Schmidt (1924) reported normal yields of 'solvents' from xylose, arabinose and glucose in a semi-synthetic medium, while Wilson and Fred (1929) reported good yields of 'solvents' from starch with beef peptone, beef aminoids, casein or casein aminoids as the source of nitrogen and obtained curves showing the typical drop in acidity.

Wynne (1931) studying the effect of acids upon the butyl-acetone fermentation, concluded that in general, complete inhibition of fermentation occurred within a pH zone of 3.9 to 3.65.

Weinstein and Rettger (1932) were unable to corroborate the observations of Robinson and found that in Robinson's medium with xylose, glucose, starch and sucrose the acidity curves produced by their organisms showed little drop following the maximum acidity. Under these conditions, the fermentations gave rise to normal yields of acetone with little or no butyl alcohol. After further investigations they concluded that a prolamine or alcohol-soluble protein is necessary in order that glucose may be fermented in a semi-synthetic medium by *Cl. acetobutylicum* and normal yields of acetone and butyl alcohol be formed.

In initiating the experiments herein reported, it became evident that the organisms used were capable of consistently producing good yields of 'solvents' from glucose in Robinson's semi-synthetic medium with only peptone as a source of nitrogen. The cultures used throughout much of the work were received from Rettger and used by Weinstein and Rettger (1932) in their investigation. It became apparent that our results were not in agreement with those of Weinstein and Rettger. It was felt desirable therefore to determine the extent to which the yields of 'solvents' produced by these organisms agree with the yields reported by other investigators and to discover, if possible, some explanation for divergent results.

METHODS

The stock medium used throughout these experiments consisted of five per cent corn mash, prepared by adding one liter of water to 50 gms. of yellow corn meal and autoclaving at 20 pounds pressure for one hour on two successive days. The loss due to evaporation was made up with sterile water and the medium distributed aseptically in sterile tubes and heated for one hour in flowing steam. The tubed medium was then incubated for four days at 37°C. before using.

Glucose was sterilized separately in aqueous solution and added to the medium at the time of inoculation.

The inorganic medium, unless otherwise noted, was that suggested by Robinson and had the following composition:

Potassium di-hydrogen phosphate	1.00 gm.
Magnesium sulphate	0.20 gm.
Sodium chloride	0.01 gm.
Ferrous sulfate	0.01 gm.
Distilled water	1,000.00 ml.

To this basal medium, were added three per cent of glucose and the source of nitrogen.

PREPARATION OF INOCULUM

The sporulated cultures, activated by pasteurizing in boiling water for 45 seconds, were inoculated into a tube of corn mash and incubated at 37°C. After vigorous fermentation had set in, one ml. transfers were made at daily intervals to fresh corn-mash tubes. After three days 10 ml. of a 24 hour corn-mash culture (unless otherwise specified) were used to start the large fermentations. Strips of filter paper were added to fermentations in liquid media, to assist in the development of anaerobic conditions. All cultures were allowed to sporulate at frequent intervals during the course of the investigation and then pasteurized, a procedure found necessary in order to maintain high solvents production.

Cultures of *Cl. acetobutylicum* used in this investigation are as follows: B, I, D, R and So received from Dr. Leo Rettger; 12A and 12B are Fernbach cultures furnished by Dr. L. M. Christensen and 14c was received from Dr. A. M. Wynne. Our appreciation is expressed to the donors.

Cultures were examined for purity at frequent intervals, and chemical analysis of the fermentation products gave added assurance that we were dealing with typical *Cl. acetobutylicum*.

Systematic study of these strains along with closely related forms has been made in this laboratory and will appear as a separate contribution. The results show that the characters of the strains used had not significantly changed from those originally described by the authors.

ANALYTICAL METHODS

Acetone was determined on aliquots of the distillate obtained as described later, by Goodwin's (1920) modification of Messinger's method.

Alcohols were determined by two methods. The first method, developed by Weyer and Rettger (1927), consists in direct distillation of an aliquot of the fermentation liquor into a cooled Babcock butter-fat bottle which is filled to the shoulder with anhydrous potassium carbonate. The 'solvents' are salted out on standing and accumulate as an oily layer

in the neck of the bottle. The volume is read in milliliters. The amount of acetone in grams, previously determined, divided by 0.7962 (specific gravity of acetone) gives the total yield of acetone in milliliters. This value, subtracted from the total volume of 'solvents,' gives the volume in milliliters of alcohol, which, when multiplied by 0.8057, (specific gravity of butyl alcohol) is converted into grams. The method assumes that the only solvents produced are acetone and butyl alcohol and that there is no volume contraction following their mixture. It provides, however, a rapid, reasonably accurate and, at least, comparable method for evaluating the 'solvents' production by the butyl organism.

In the second method, an aliquot is distilled using an iced condenser. The distillate is made alkaline to phenolphthalein and redistilled, the second distillate is brought accurately to a volume of 200 ml. with distilled CO_2-free water. Aliquots of the distillate are used for the determination of acetone as previously mentioned.

For the determination of acetone and ethyl alcohols in the distillate, an unpublished method developed by Stahly, Osburn and Werkman based on oxidation of the alcohols and determination of the acids in the resulting solution by partition with ethyl ether, was used. The method consists in adding 50 ml. of the distillate to 10 gm. of potassium dichromate and 25 ml. of ortho-phosphoric acid (85 per cent) contained in a 200 ml. balloon flask. The flask is connected to an efficient reflux condenser and heated at such a rate that the mixture is brought to a boil in two minutes. Gentle boiling is continued for six minutes and the flask cooled and transferred, (after washing down the reflux condenser) to a Leibig condenser. Distillation is continued until the residue foams and nearly fills the flask. The distillate is made up to a volume of 200 ml. and aliquots of the acid solution are partitioned with ethyl ether. From the constants so determined, the percentages of butyric and acetic acids in the acid distillate are determined and hence the quantities of butyl and ethyl alcohols in the neutral distillate.

In all cases, 'solvents' are reported in percentage by weight of the substrate added.

Titrable acidity was determined by diluting 10 ml. aliquots of the liquor to 50 ml. with CO_2-free distilled water, heating to boiling and titrating with 0.05 normal NaOH in the presence of phenolphthalein.

Oxidation-reduction potentials were determined by the use of the electron tube potentiometer as described by Werkman, Johnson and Coile (1933).

Determinations of the pH were made with the electron tube potentiometer and quinhydrone electrode.

Zein was prepared in the following manner. Corn gluten is extracted continuously for 48 hours with ethyl ether to remove the corn oils and other fatty constituents. The residue is extracted for an additional 48 hours in a stream of water and after drying, provided the base for the extraction of the zein. The latter is accomplished with two to three extractions by decantation, using 85 per cent ethyl alcohol and allowing the gluten to remain in contact with the alcohol for 48 hour periods. The alcohol is partly removed from the resulting solution by distillation at 50 to 55°C. under reduced pressure. The zein precipitates from the resulting syrupy solution by pouring it slowly into ice cooled water containing a small amount of salt, and is purified by resolution in alcohol followed by a second precipitation. The product gives positive biuret and xanthoproteic reactions.

EXPERIMENTAL

The first series of fermentations was set up as an orientating experiment, and was carried out in 500 ml. cotton stoppered flasks containing 400 ml. of medium. Each flask was inoculated with 10 ml. of a 24 hour corn-mash culture of strain I. Analyses were made after 96 hours. The results of this experiment are shown in table 1.

TABLE 1. *Production of 'solvents' from glucose in Robinson's medium with various nitrogen sources*

No.	Robinson's medium with 3 per cent glucose plus	Alcohol by salting out	Acetone	Alcohols by oxidation	
				EtOH	BuOH
1		— —	6.34	5.03	17.59
2	Aqueous extract of 20 gm. corn gluten	15.58	5.83	1.30	17.87
3	Aqueous extract of 20 gm. gluten + 20 gm. pulped filter paper	13.70	6.40	1.17	15.21
4	5 per cent yeast	— —	4.51	1.58	15.53
5	5 per cent corn zein	— —	6.80	1.02	14.80
6	1 per cent corn zein	— —	5.19	0.22	13.78
7	5 per cent corn mash only	17.98	7.02	1.20	19.49

The data in table 1 show no significant difference in the yields of 'solvents.' In view of these results, unlike those obtained by Weinstein and Rettger (1932), it seemed desirable to follow the course of the acidity produced in glucose medium. One-liter flasks each containing 800 ml. of Robinson's inorganic medium with 0.5 per cent Bacto peptone and 3 per cent of glucose (C.P.), were inoculated with 10 ml. of a 24 hour corn-mash culture of the various strains of *Cl. acetobutylicum*. The flasks were so arranged that samples could be withdrawn at intervals and the acidity determined.

The results presented in table 2 and in part in figure 1 show reasonably sharp breaks in the acidity curves in all cases, with the possible exception of strain So. This is in good agreement with the results of Robinson (1922) but fails to confirm those of Weinstein and Rettger who found little decline in the acidity curve following its maximum when the organisms were grown in the mineral medium with peptone as the only source of nitrogen.

Four of the previously used cultures, B, I, K and St were then inoculated into flasks containing 400 ml. of Robinson's medium with 3 per cent glucose. A 5 per cent corn mash control was run and 'solvents' determined after four days' incubation at 37°C. The results are shown in table 3.

In all of these fermentations good yields of 'solvents' were obtained from glucose in Robinson's medium. It will be noted that in all cases the yields of ethyl alcohol in the glucose medium were markedly higher than in the corn mash. In a report by Wilson and Fred (1929) it was observed that when starch is fermented in a medium containing only peptone as a source of nitrogen, there is a slight rise in the acetone at the expense of ethyl alcohol.

TABLE 2. *Rate of acid production in Robinson's medium**

Strain	B	I	K	R	So	St	12A	12B
Time in hrs.								
0	3.00	3.00	3.00	3.25	3.60	2.95	3.20	3.25
14	8.05	7.40	8.10	8.20	8.85	6.40	3.30	3.30
19.5	8.80	9.10	9.00	8.90	11.20	9.00	3.40	3.30
23.5	8.60	8.70	8.20	8.40	11.70	9.10	3.65	3.30
27.5	7.55	8.20	6.75	6.30	11.90	9.10	3.90	3.60
31.5	7.30	7.00	6.40	6.90	12.00	9.50	5.50	3.70
40.0	6.10	6.00	6.00	6.10	12.00	6.60	9.20	6.25
46	6.00	6.20	6.00	6.60	11.50	6.30	10.50	8.90
52	5.90	6.40	6.00	6.80	11.30	6.60	10.20	11.10
56.5	6.20	7.00	6.30	7.10	11.30	6.50	9.40	11.50
65.5	6.60	6.60	6.30	6.70	11.10	6.70	8.00	10.20
71.5	6.50	6.30	6.20	6.70	10.50	6.90	7.60	9.50
79	6.10	6.40	6.10	6.70	10.40	6.70	8.50	9.10
91.5	6.30	6.20	6.00	6.70	10.40	5.90	8.50	8.70

* Cc. 0.1 N KOH per 10 cc. culture.
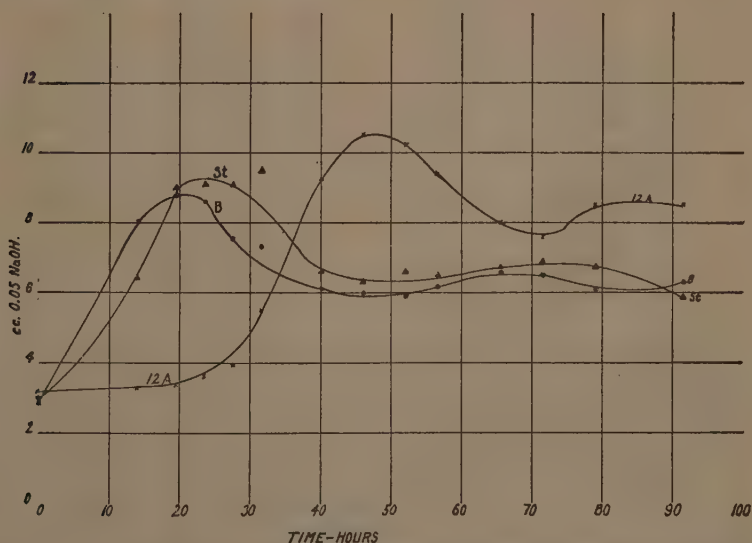
Fig. 1. Acid production by *Cl. acetobutylicum* from glucose in Robinson's medium.

It is difficult to advance any satisfactory explanation for the contradictory findings. Those who have worked with these organisms are familiar with the occasional wide variations which sometimes occur in two fermentations started with aliquots of the same original culture and carried out under conditions identical in all determinable respects. Thus, one flask may show the typical break in acidity while the second maintains an abnormally high value, or one fermentation may be vigorously under way in six to eight hours while the second shows a preliminary lag phase of 24 to 48 hours. With such results, under conditions which are identical in so far as determinable, it would however, be illogical to assume no cause

for these variations or to believe that conditions are identical. It would seem necessary to conclude that accompanying such results, there is some condition or set of conditions, differing in the two flasks, which eluding our methods of detection, still plays an important role in the behavior of the organism. Any attempted explanation of these factors or their biological significance would be, at this time, in the realm of speculation. We may suggest, however, that some of the divergent results reported in the literature may find explanation in some such set of undetermined factors which may have been maintained, under certain conditions, throughout the entire course of an investigation.

TABLE 3. *'Solvents' production by four strains of Cl. acetobutylicum from glucose in Robinson's medium*

Strain	Medium	'Solvents' by salting out	Acetone	Alcohols by oxidation	
				EtOH	BuOH
B	glucose	19.16	6.26	4.05	14.38
	corn mash	14.60	5.46	1.94	13.01
I	glucose	16.83	7.25	4.03	16.33
	corn mash	11.60	4.04	1.01	9.69
K	glucose	17.83	6.87	4.22	14.79
	corn mash	——	4.80	1.17	12.30
St.	glucose	18.15	7.31	4.81	17.21
	corn mash	14.10	5.18	1.05	13.15

The next results to be reported were taken from an earlier series of experiments set up for the purpose of following the course of 'solvents' production and accompanying factors such as acidity and oxidation-reduction potential. A few of these results have been chosen to illustrate the points just discussed and to show the variations which may occur in fermentations carried out under conditions as nearly identical as possible.

The fermentations were carried out in two-liter flasks containing 1,800 ml. of the following medium: glucose, 3 per cent, di-basic potassium phosphate 0.1 per cent, and Bacto peptone 0.5 per cent. The flasks were arranged so as to permit samples to be withdrawn aseptically and to determine the oxidation-reduction potentials. The inoculum consisted of 50 ml. of an actively gassing 15 to 20 hour culture of strain 14c in the above medium. 'Solvents' were determined by the Babcock cream-bottle method. Corn and gluten extracts were added as shown in the tables.

The data from two of these experiments have been collected in tables 4 and 5. An examination of these data brings out several interesting facts. In each case, the fermentation which gave low solvent yields was accompanied by a relatively low final pH and an acidity curve failing to show the characteristic break, whereas the fermentations giving normal yields of 'solvents' had a final pH above 4 in each case and the accompanying acid curves show a pronounced break. The acidity curves accompanying

the poor 'solvents' producing fermentations will be seen to resemble those obtained by Weinstein and Rettger (1932).

TABLE 4. *Titrable acidity, Eh and pH of glucose fermentations by strain 14c, with gluten extract added. Acetone extract from 72 gm. of gluten added to each*

Time hours	1.					2.				
	Eh	pH	T.A.	Acetone	Butyl alcohol	Eh	pH	T.A.	Acetone	Butyl alcohol
2	+.089	6.1	0.6			—.091	6.4	0.3		
2.5										
4	+.043					—.114	6.4	0.3		
5										
6	—.030	6.1	0.6							
7.5						—.114				
8	—.074									
9						—.239	6.3	0.3		
10	—.162	5.95	0.65							
12.5						—.288	5.2	0.5		
13	—.220	5.5	0.7							
16	—.227	4.75	1.0	0.17	0	—.278	4.4	1.0		
19	—.207	4.2	1.3							
23	—.220	4.0	1.5	0.08	0	—.257	4.1	1.5		
27	—.215									
30						—.239	4.3	1.3		
32	—.186	3.9	2.2	0.57	0					
36						—.244	4.5	0.9		
41.5	—.182	3.75	2.3			—.248	4.5	0.9		
48	—.169	4.0	2.3	0.57	0	—.248	4.4	0.9	7.40	11.42
54.5	—.167	3.7	2.3	1.59	0	—.242	4.5	0.9		
63						—.086	4.5	1.0	7.56	13.94
67	—.070	3.7	2.3	3.41	2.86		4.4	1.0		
76.5						—.086				
97						—.047				
130						—.041	4.1	1.0	8.32	20.42

It will be remembered that Wynne (1931) reported complete inhibition of the butyl-acetone fermentation resulted from high acidities represented by the pH range of 3.9 to 3.65. In the above data it will be observed that in both of the poor fermentations the pH had fallen below 3.9 before the end of 40 hours. Comparing these fermentations with the good 'solvents' producing fermentations it is seen that in the latter case the appearance of acetone and butyl alcohol is practically limited to the period between 40 hours and the end of the fermentation. This relation suggests the probability that a pH less than 3.9 has an inhibitory effect upon the enzymes involved in the reduction of the acids to alcohols.

A further examination of tables 3 and 4 shows a correlation between the oxidation-reduction potentials during the course of the fermentation and the 'solvents' production. In both cases where the production was good, the organisms were able to develop a negative Eh more rapidly and maintain it at a lower level for a longer period of time than fermentations responsible for the low 'solvents' production. As has been previously mentioned, there appears to be no satisfactory explanation for these variations in fermentations which should be identical.

Since the preliminary experiments indicated that normal 'solvents' production could take place from glucose in a semi-synthetic medium, it

TABLE 5. *Titrable acidity, Eh and pH of glucose fermentations by strain 14c, with corn extracts added. Butyl alcohol extract from 72 gm. of corn added to each*

Time hours	1.					2.				
	Eh	pH	T.A.	Acetone	Butyl alcohol	Eh	pH	T.A.	Acetone	Butyl alcohol
2	+.243		0.6							
2.5						—.244				
4.43	+.143									
5						—.300	5.4	0.4		
6	+.034	6.3	0.6							
7.5						—.245				
8	+.103									
9						—.222	4.5	1.0		
10	—.001	6.3	0.6							
12.5						—.211	4.5	1.3		
13	—.197	5.95	1.5							
16	—.233	4.75	1.0			—.215	4.1	1.4		
19	—.198	4.25	1.3							
23	—.189	4.25	1.3	0	0	—.198	4.2	1.6	0.34	0
27	—.187									
30						—.177	4.3	1.4		
32	—.191	4.4	1.9	0.57	0					
36						—.185	4.3	1.3		
41.5	—.141	3.8	2.0	0.34	0	—.196	4.4	1.1		
48	—.059	3.9	2.3			—.192	4.4	1.0	4.70	6.05
54.5	+.018	3.75	2.5	0.57	0	—.167	4.4	1.0		
63						—.162	4.4	1.0	7.73	13.77
67	+.203	3.75	2.3	1.01	5.26					
76.5						—.043	4.5	1.0		
97						+.113				
130						+.148	4.5	1.0	9.91	18.76

appeared desirable to determine to what extent the other results reported by Weinstein and Rettger could be duplicated, or to determine if possible, the conditions leading to the production of normal quantities of acetone accompanied by little or no alcohol.

Weinstein and Rettger have taken exception to results reported by Peterson, Fred and Schmidt (1924), who obtained normal yields of 'solvents' from glucose, arabinose and xylose in a semi-synthetic medium. Weinstein and Rettger suggested that the normal fermentations met with there were possibly due to the introduction of sufficient zein with the corn mash inoculum. To test the correctness of this suggestion the following experiment was carried out. Strains B, I, K and St were transferred serially four times through tubes of Robinson's medium containing 3 per cent glucose. The fourth tube of each culture (in duplicate) was used as the inoculum for 400 ml. fermentations of glucose in Robinson's medium with corn mash controls. The results are shown in table 6.

It will be seen that the 'solvents' yields from glucose in Robinson's medium are comparable with those derived from corn mash and practically the same as those shown in table 3 where the media were inoculated with corn mash cultures. Since passage of the inoculum through four successive tubes of glucose-peptone medium eliminates all but traces of corn zein, it is evident that the yields cannot be explained by the introduction of such an alcohol soluble protein with the inoculum.

Weinstein and Rettger have reported further that the removal of the alcohol-soluble proteins from corn by extracting repeatedly with alcohol

and using the extracted corn as a substrate, resulted in normal yields of acetone while the alcohol yield dropped to from two to four per cent as compared with an average of about 13 per cent for the corn mash controls. We have repeated these experiments and failed to obtain the type of results reported by these investigators.

TABLE 6. *'Solvents' production from glucos in Robinson's medium following four successive transfers of the inoculum in glucose medium*

Strain	Medium	Alcohol by salting out	Acetone	Alcohols by oxidation	
				EtOH	BuOH
B	glucose	17.34	6.07	3.07	16.34
	corn mash	12.50	6.00	0.84	13.66
I	glucose	16.17	6.51	4.57	15.27
	corn mash	15.64	6.82	1.53	14.67
K	glucose	19.82	6.95	3.56	17.47
	corn mash	14.10	6.38	1.83	13.65
St.	glucose	16.50	6.91	4.41	16.56
	corn mash	17.10	6.60	1.14	14.78

Yellow corn meal was extracted continuously for 24 hours with ethyl ether, followed by repeated extractions with 85 per cent ethyl alcohol by decantation. Nine extractions were made; each addition of alcohol was allowed to remain in contact with the corn meal for 12 hours before decantation. The last two extractions were colorless and the resulting corn meal was white. The extracted corn meal, after drying was made into five per cent mash and flasks of this medium along with normal corn mash controls were inoculated with 24 hour cultures of strains B, I, K, and St. After four days at 37°C. the fermentations were analyzed for 'solvents'. The results are shown in table 7.

TABLE 7. *'Solvents' production by Cl. acetobutylicum in alcohol-extracted corn*

Strain	Medium	Alcohol by salting out	Acetone	Alcohols by oxidation	
				EtOH	BuOH
B	extracted corn	12.30	4.92	1.61	11.22
	corn mash control	14.25	6.18	1.14	15.93
I	extracted corn	11.67	5.14	1.39	12.66
	corn mash control	15.45	6.59	1.23	15.27
K	extracted corn	12.80	4.83	2.37	12.60
	corn mash control	11.35	5.42	1.60	13.49
St.	extracted corn	13.85	5.82	2.04	13.38
	corn mash control	13.35	6.69	0.96	15.26

The data in table 7 show some differences between the fermentation of the unextracted corn and that which was previously extracted with alcohol. Fermentation of the alcohol extracted corn gave a total 'solvents' yield somewhat lower than the corn mash control. The acetone and butyl alcohol yields are lower while the ethyl alcohol is slightly higher than with the unextracted corn. With the exception of these minor variations, however, the results are comparable and would be considered typical of *Cl. acetobutylicum* fermentation.

Since it appears that the formation of acetone and alcohols are to some extent, at least, independent processes, the possibility that the addition of toxic compounds to the fermentation might lead to a greater inhibition of one process than the other was considered. To test this suggestion, four one-liter flasks, each containing 600 ml. of Robinson's medium with 3 per cent glucose were inoculated with 20 ml. of a 24 hour corn mash culture of strain St. The acidity was followed in each flask, and immediately following the break in the acid curve (about 36 hours in all cases), flasks 2, 3 and 4 were treated respectively with one ml. of croten aldehyde, one ml. of chloroform and one ml. of toluene. Gassing and the head disappeared in less than two hours in the flasks receiving chloroform and toluene while the one receiving croten aldehyde showed vigorous gassing for about five hours following the addition. After four days incubation aliquots of the liquor were taken for the determination of 'solvents'. The results are shown in table 8.

TABLE 8. *'Solvents' production in glucose-peptone medium. Protoplasmic poisons were added 36 hours after start of fermentation*

No.	Treatment	Acetone percentage	Alcohols by oxidation	
			EtOH percentage	BuOH percentage
1	Control	6.84	2.18	19.82
2	Croton aldehyde	7.03*	2.93	11.55
3	Chloroform	7.92*	1.49	16.06
4	Toluene	5.92	1.63	13.06

* High acetone value due to chloroform and croton aldehyde.

The results show that, although the total 'solvents' yields are considerably lower in fermentations receiving additions of toxic substances, the acetone-alcohol ratio is not greatly changed.

In order to test the utilization of water insoluble proteins as a source of nitrogen, five per cent casein, and egg albumin and zein were added to flasks containing 400 ml. Robinson's inorganic medium with three per cent glucose. The flasks were inoculated with strain I and incubated for four days. Two glucose-peptone controls were run simultaneously. Although the controls gave normal yields of 'solvents' there was only a slight production in the flasks containing the water-insoluble proteins as nitrogen source, although each of the latter showed a transitory fermentation lasting about 24 hours.

During the autoclaving of the above protein media it was apparent that a certain amount of hydrolysis had taken place. This suggested the possibility that the transitory fermentations observed with these proteins might have arisen from the utilization of small amounts of hydrolytic products arising during autoclaving. To determine whether these organisms are able to utilize simple amino acids, hydrolysates of the above proteins were prepared by refluxing the various proteins for 36 hours with five times their weight of sulfuric acid (1 to 3). The resulting solution was

freed of sulfuric acid by adding an excess of calcium carbonate and filtering off the precipitated calcium sulfate. The filtrates were concentrated to 200 ml. and aliquots added to flasks containing Robinson's inorganic medium and three per cent glucose. Typical results of these fermentations are shown in table 9.

TABLE 9.   *Solvents production from glucose with protein hydrolysates as the source of nitrogen*

Strain	Nitrogen source	Acetone	Alcohols by oxidation	
			EtOH	BuOH
1.	5 percent hydrolized casein	7.80	2.28	15.92
St	3 per cent hydrolized casein	1.54	0.80	1.95
St	3 per cent hydrolized albumin	7.34	1.03	15.27
St	2 per cent hydrolized albumin	2.16	1.76	9.47
St	5 per cent hydrolized zein	1.30	0.72	4.36
St	2 per cent hydrolized zein	1.70	3.87	4.09
St	Peptone control	7.29	4.73	17.29

The results have not been consistent when amino acid mixtures were used as the only source of nitrogen. Further work, on the conditions accompanying the utilization of amino acids may offer an explanation, while the relatively high yields occasionally found are, at least, positive indication that such amino acid mixtures are capable of serving as nitrogen sources for the butyl organism.

SUMMARY AND CONCLUSIONS

Fermentations have been carried out with seven strains of *Clostridium acetobutylicum* which have been systematically studied in this laboratory. Analyses of fermentations of glucose produced in the preliminary experiments have shown the production of normal yields of 'solvents' and that the organisms used were typical *Cl. acetobutylicum*. In Robinson's semisynthetic medium with three per cent glucose all strains gave characteristic titrable acidity curves showing a pronounced drop following the peak. In the same medium, consistently good yields of 'solvents' have been obtained. All attempts to secure acetone-alcohol ratios such as those reported by Weinstein and Rettger (normal acetone yields with little or no alcohol) have failed.

In those occasionally occurring abnormal fermentations, in which low yields of 'solvents' are found, the fermentation is accompanied by factors which deviate from the normal, such as a failure of the acidity to break and a final pH lower than 3.9. Further, it appears that the normal fermentation is accompanied by a more reduced oxidation-reduction potential than the low 'solvents' producing fermentation.

Attempts to bring about the fermentation of glucose in Robinson's inorganic medium with such water insoluble proteins as egg albumin, casein

and zein serving as the only source of nitrogen were not successful. When hydrolysates of these proteins were used as the nitrogen source the results were inconsistent. In conclusion, it appears that some factor or group of factors, other than those commonly studied and controlled, plays an important part in determining the course of the butyl-acetone fermentation.

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THE EFFECT OF DRY-CLEANING AND MECHANICAL CLEANING UPON FURS[1,2]

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This paper is a progress report of research which is being done by the Department of Textiles and Clothing on the effect of mechanical cleaning and dry-cleaning upon furs.

A limited amount of research has been done on the cleaning of furs and as far as it has been possible to determine, no work has been reported on the deterioration of the hair as the result of cleaning.

Goldman and Hubbard (2) of the United States Bureau of Standards experimented with the dry-cleaning of eight different furs; namely, beaver, fox, squirrel, Hudson seal, caracul, wolf, muskrat and raccoon. Two specimens of each of the furs were cleaned with naphtha and two with naphtha and paraffin. Each group was run for ten minutes, then extracted in a centrifuge and dried. After the cleaning, the appearance of the second group was good. The ether-soluble content of the cleaned furs and of the two untreated specimens was obtained. All of the "fat-free" specimens were next cleaned with a solution of paraffin and naphtha in one to forty proportion. The appearance of the furs was not injured. The specimens were again extracted with ether to determine the amount of fat which had been replaced by the paraffin. The results indicated that the loss in ether soluble content was small except in the case of raccoon.

Sowerwine (6) studied the effect of dry and mechanical cleaning upon ten different furs. Her results showed, in the case of dry-cleaning—using the formula worked out by Goldman and Hubbard, an increase in gloss due to the use of the paraffin and, an average decrease in the breaking strength and elasticity of the furs. There was practically no change in the mechanically cleaned furs.

According to Bachrach (1), who has examined thousands of specimens, the interior physical structure of hair and fabric undergoes few changes as the result of ordinary trade procedure. This structure is usually broken down by rough treatment.

Hausman (3) finds that external friction frequently causes alteration

in the form of scales. Usually the scales at the base of the hair are of greater longitudinal and transverse diameter than those at the tip of the shaft. The changes in scales are usually found in protective hairs rather than in the under hairs of the pelt.

Hausman's (5) experiments show that "the hair shaft consists of four structural units: (1) the medulla or pith, built up of many shrunken and varioiusly disposed cells or chambers representing dried and cornified epithelial structures connected by a branching filamentous network, which sometimes completely fills the medullary column, but which is interrupted in many cases; (2) the cortex or shell of the hair shaft surrounding the medulla composed of elongated fusiform cells or hair spindles, coalesced together into a horny almost homogeneous, hyaline mass and forming in many cases, where the medulla is reduced, a large proportion of the hair shaft; (3) the pigment granules to which the color of the hair is primarily due (though in some hairs the pigment is diffuse and not granular in form) scattered about within or between the hair spindles and in some hairs arranged in definite patterns; and (4) the cuticle, or outermost integument of the hair shaft lying upon the cortex, and composed of imbricated, thin, hyaline colorless scales of varying forms and dimensions. It is the forms, relationships and measurements of these four elements together with the measurements of the diameter of the hair shaft itself in micra which constitute the series of determinative criteria for each species of hair."

Hausman's (4) microscopic study of the hair shows that it is strengthened by the cortex and that the greater the cortex in proportion to the medulla the greater is the resistance of the hair to wear. The medulla is an element of weakness in the composition of the hair shaft, being composed of empty or practically empty cells, frequently with disconnected strands of elastic substance running between them. Therefore, if the medulla is large in proportion to the cortex, the hair is nearly a hollow cylinder and is easily broken. As soon as the scales of a hair are worn off the cortex is soon injured and the hair shaft deteriorates rapidly. With hairs having large medullas, wear begins much earlier than it does in hairs having small or no medullary columns.

Hausman discovered by testing fur with an attritometer that unclipped furs are superior to clipped furs. Hair which has not been clipped does not wear until after the hair breaks or portions of the protecting cuticle are injured by wear.

There is some variation in the cortex of the hair of different species of fur-bearing mammals which makes it less resistant than the hair of other mammals. The quality of the keratin of the cortex cells and their fusion probably accounts for this variation.

EXPERIMENTAL

Ten furs were selected for experimental purposes; namely, Hudson Seal, Northern Seal, opossum, skunk, muskrat, beaver, squirrel, rabbit, fox and raccoon. Salt alum tannage was used for the furs and the specimens tested were taken from the backs of the pelts and matched in quality as closely as possible.

For the sake of accuracy the controls in each of the four sets were averaged for each test. The following tests were run on the furs in allotment I during the year 1930-1931.

The ether-soluble content of each of the ten different furs in the con-

trol and cleaned groups was determined by ether extraction, and the average deviation from the control was calculated. The furs were heated to constant weight at 105°C., extracted with anhydrous ether in a Soxhlet extractor for eighteen hours, air-dried, and heated to constant weight again. The weighings were made by the method of tares.

Shrinkage was determined by blocking off a one-inch square and measuring it before and after cleaning.

The thickness of the skin was determined by means of a micrometer. Ten determinations from each of the ten kinds of fur were made from both the control and cleaned furs, and the average deviation from the control was calculated.

The diameter of the hair was determined on both control and cleaned furs by means of a micrometer. For each kind of fur, ten determinations were made and the averages calculated.

Change in the color of the dyed furs, caused by cleaning, was determined by the use of a reflectometer. In each case four determinations were made and the averages calculated.

Change in gloss, caused by the use of paraffin in dry-cleaning, and Polar Bear Meal in mechanical cleaning, was determined by means of a glarimeter. Three readings were taken with the flow of the hair going upward and three with the flow going downward. Averages were determined and the deviation from the control calculated.

The number of hairs to the square inch was determined by pulling out hairs and counting. Three determinations with averages were made of hair from each kind of fur.

Length of hair was determined by measuring separately with a linear steel scale both the guard hairs and the under hairs. Ten determinations of each were made and averages calculated.

Breaking strength and elasticity of the furs were determined by the strip method with the Scott Universal Tester (8). The specimens were taken from different portions of the pelt. The tests were run at a temperature of 71°F. and 80 per cent humidity. Five determinations were made of each of the ten kinds of fur in both the control and the cleaned groups, and the average deviation from the control was calculated.

Wear, caused by abrasion, was determined on both control and cleaned furs with the Wyzenbeck Precision Wear Tester. The specimens were weighed air dry and given 1,500 double rubs, then weighed again immediately after testing. Three determinations of each of the different furs were made and the average loss in weight and the deviation from control calculated.

Dry-cleaning was done by the formula given in Technical Bulletin No. 35, National Association of Dyers and Clearners (7).

The specimens of fur were placed in the washer in a solution of Stoddard Dry-Cleaning Solvent, and run for ten minutes. As soon as the dirt was loosened, the fur was placed in a centrifuge and whirled for approximately one minute, long enough to extract all naphtha. The strips were then placed in a solution of paraffin in Stoddard Dry-Cleaning Solvent and allowed to soak for one minute, being gently manipulated to assure even penetration. A cotton cloth was placed in the paraffin solution to absorb any water which it might contain. The strips were again centrifuged for one minute. When removed, they were shaken well and hung in a ventilated dry-room at a temperature of 100°F.

Mechanical cleaning was done by putting the furs into a large drum,

called a cleaning drum, along with fur coats. Approximately five gallons of ''Polar Bear Meal,'' a corn product, was placed in the drum with them. The furs were tossed in the cleaning drum for one and one-half hours, next placed in an open drum, and tossed for one and one-half hours in order to shake the meal from the fur. After cleaning, the furs were glazed by brushing the fur against the flow of the hair with a stiff brush which had been dipped into water and then shaken. The fur was next combed with a wire brush and hung on a rack, at room temperature. After the fur was dry, it was laid upon a padded table and beaten with bamboo sticks. This process removed any remaining cleaning meal and also fluffed up the fur, giving it a light airy appearance.

Microscopic examination of scales and medulla were made of both control and cleaned furs. Slides were made of scales and of both crosswise and lengthwise sections of guard hairs and under hairs.

In making slides of these sections the hairs were boiled for one-half hour in a fast red dye. Those to be used for cross sections were tied in bundles and cleared with xylol. To remove the water, they were run through chloroform and then through ether. The bundles of hair were then embedded in celloidin until ready to cut. They were next put into a mixture of 95 per cent ethyl alcohol and glycerin, in equal proportions until slightly softened.

These blocks were then cut in the microtome into sections measuring from fifteen to twenty microns. The cut sections, except the cross sections of the under hair, were put into 95 per cent alcohol and acetone to dissolve the celloidin. Carbol-xylol and lastly pure xylol was used to clear the sections before mounting them in balsam on the glass slides.

In order to see the scales more clearly, glycerin mounts were made of the hairs. These mounts were made by putting the hair into a solution of pure glycerin and absolute alcohol and allowing the mixture to evaporate to the consistency of pure glycerin over a waterbath. The slides were then made by putting a hair, together with some of the jelly, on a glass slide, and covering all with a cover glass which was cemented on with a coverglass cement. Photomicrographs were made from the slides by means of a Leitz photomicrographic camera.

In the fall of 1931 the furs were taken from cold storage. One control, one mechanically cleaned and one dry-cleaned set were put aside for testing. The remaining furs with the exception of the controls were again cleaned, after which, one set of each of the mechanically cleaned and drycleaned furs was also put aside for testing, and the furs not tested were again placed in cold storage.

The tests which were used in 1930-1931 were repeated on the second allotment of furs in 1931-32 and on the third allotment in 1932-33. Each year deviations were determined from previous results.

DISCUSSION OF DATA

In all cases the mechanically cleaned furs lost more than the drycleaned furs by ether extraction. The first dry-cleaning took the greater proportion of the fat from the specimens. This fact would indicate that the original ether-soluble content of the furs was not replaced after cleaning. In the case of every fur, the loss of fat from dry-cleaning was greater than from mechanical cleaning.

Raccoon showed a greater deviation in loss of fat than any of the
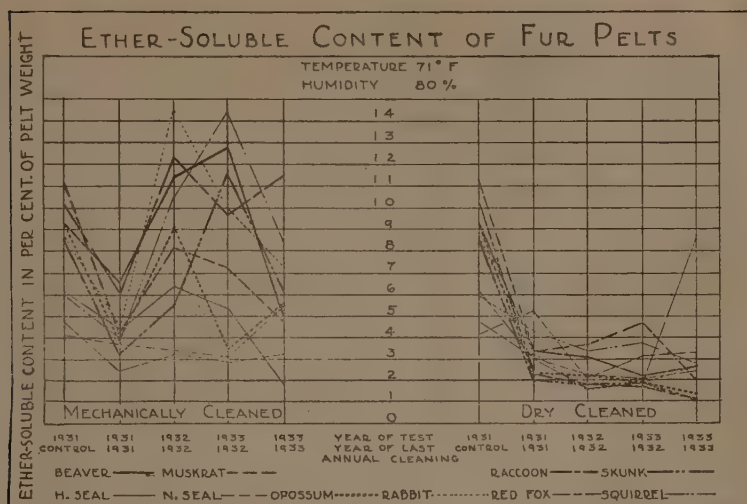
Fig. 1. Ether-soluble content of pelts.

furs. It also lost less weight than any of the other dry-cleaned specimens. Goldman and Hubbard (2) obtained similar results for raccoon.

In most cases the mechanically cleaned furs maintained a greater average breaking strength, but the difference was not pronounced except in the case of raccoon. Raccoon had the greatest average breaking strength of all the furs and Hudson seal had the least breaking strength. The average results in breaking strength were in favor of mechanical cleaning.

In general, the average elongation of fur was greater in the mechanically cleaned specimens. Raccoon showed greater variation in elongation in both processes than the other furs. With the exception of beaver, both mechanically cleaned and dry-cleaned furs showed a definite increase in elongation after the first cleaning, which dropped to nearly normal after storage and later cleanings.

Both mechanically cleaned and dry-cleaned furs showed a definite loss in thickness after the first cleaning, but they increased in thickness with later cleanings. Raccoon was the only fur to lose in thickness from both types of cleaning. The average thickness of all the furs was slightly greater for the mechanically cleaned furs than for the dry-cleaned furs.

The average loss in weight from abrasion was greater, in most cases, for the dry-cleaned furs than for the mechanically cleaned furs. In all groups, the least average loss in weight was found in beaver, the greatest average loss in weight was found in opossum. In general, the soft-haired furs lost more in weight than the coarser furs which had a greater number of guard hairs.

The average loss in weight from abrasion after three cleanings was greater in the dry-cleaned furs than in the mechanically cleaned furs.

The average gloss of the dry-cleaned furs was higher than that of the mechanically cleaned furs.

Length of hair did not seem to be materially affected by cleaning.

TABLE 1. Average percentage of color reflection of dyed furs with deviation from control

Kind of fur	Control 1931 Reflection factor	Tested in 1931 Cleaned in 1931 Reflection factor	Deviation from control Difference	Pctg.	Tested in 1932 Cleaned in 1931 Reflection factor	Deviation from control Difference	Pctg.	Cleaned in 1932 Reflection factor	Deviation from control Difference	Pctg.	Deviation from 1931 Difference	Pctg.
Mechanically cleaned												
Hudson Seal	0.01913	0.0170060	−0.002124	−11.10	0.01534	−0.00379	−19.8	0.017803	−0.00133	−6.9	+0.000797	+4.6
Northern Seal	0.01983	0.0181426	−0.001687	−8.51	0.02373	−0.00390	+19.7	0.020310	+0.00048	+2.4	+0.002168	+11.9
Dry cleaned												
Hudson Seal	0.01913	0.024109	+0.004979	+26.03	0.02866	+0.00953	+49.8	0.03463	+0.01550	+81.02	+0.01053	+43.85
Northern Seal	0.01983	0.024838	+0.005009	+25.26	0.02653	+0.00670	+33.7	0.03613	+0.01630	+82.19	+0.01130	+45.13

TABLE 1. (Continued)

Kind of fur	Tested in 1933 Cleaned in 1933 Reflection factor	Deviation from control Difference	Pctg.	Deviation from 1932 Difference	Pctg.	Average readings of cleaned furs Difference	Average of deviations Pctg.
Mechanically cleaned							
Hudson Seal	0.003487	−0.015643	−81.77	−0.014316	−80.41	0.013409	−29.89
Northern Seal	0.008845	−0.010995	−55.40	−0.011465	−56.45	0.017757	−10.45
Dry cleaned							
Hudson Seal	0.015366	−0.003764	−19.68	−0.01927	−55.64	0.102765	+34.29
Northern Seal	0.016977	−0.002853	−14.39	−0.01916	−53.03	0.026119	+31.69

TABLE 2. *Deviation of average gloss of furs from year to year*

Kind of fur	Control	Cleaned and tested in 1931	Cleaned in 1931 and 1932	Tested in 1932	Cleaned in 1931, 1932 and 1933		Tested in 1933	Average gloss of cleaned furs	Average deviation from control
		Deviation from control	Deviation from control	Difference in deviation	Deviation from control	Difference in deviations	Difference in deviations		
	Degrees	Percentages	Percentage	Percentage	Percentage	Percentage	Percentage	Degrees	Percentage
Mechanically cleaned									
Beaver	12.07	+24.9	+24.4	−0.5	+38.2	+13.3	+13.8	15.59	+29.2
Red fox	19.28	−43.3	+31.7	+75.0	−45.3	−2.0	−77.0	15.62	−18.9
Muskrat	18.23	−2.1	+47.8	+49.9	+43.7	+45.8	−4.1	23.66	+29.8
Opossum	21.04	+6.7	+4.1	−2.6	−35.4	−42.1	−39.5	19.32	−8.2
Rabbit	25.45	−0.7	+5.2	+5.9	−27.8	−27.1	−33.0	22.60	−11.2
Raccoon	19.58	+17.4	+24.1	+6.7	−33.6	−51.0	+57.7	24.48	+2.6
Hudson Seal									
Northern Seal									
Skunk	33.32	+6.9	−16.9	−23.8	−29.2	−36.1	−12.3	28.98	−13.1
Squirrel	33.36	−29.9	−12.8	+17.1	−13.4	+16.5	−0.6	27.12	−18.7
Dry cleaned									
Beaver	12.07	−6.4	+163.9	+170.3	+51.4	+57.8	−112.5	20.47	+69.6
Red fox	19.28	−35.1	+11.1	+46.2	+42.4	+77.5	+31.3	20.46	+6.1
Muskrat	18.23	+4.7	+18.3	+13.6	+37.7	+33.0	+19.4	21.91	+20.2
Opossum	21.04	+99.6	+32.3	−67.3	+29.1	−70.5	−8.2	32.33	+53.6
Rabbit	25.45	−2.4	+0.3	+2.7	+37.1	+39.5	+36.8	28.42	+11.6
Raccoon	19.58	+25.2	+2.7	−22.5	+55.3	+30.1	+52.6	25.01	+27.7
Northern Seal									
Hudson Seal									
Skunk	33.32	−12.4	−30.7	−18.3	−27.5	−15.1	+3.2	25.47	−23.5
Squirrel	33.36	−19.3	−15.8	+3.5	−14.4	+4.9	+1.4	27.85	−16.5

Note: Gloss on Hudson Seal and Northern Seal could not be determined because it was impossible to get satisfactory reflection on the black furs.
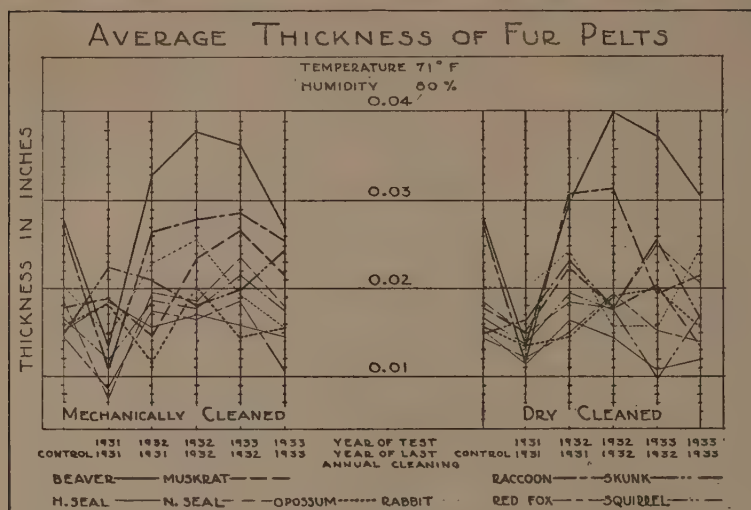
Fig. 2.   Average thickness of fur pelts.

TABLE 3.   *The number of hairs per square inch of pelt*

| Kind of fur | Guard hair | Under hair | |
	Average	Average	Total
Beaver	432	117,180	117,612
Red fox	1,589	39,525	41,114
Muskrat	3,605	102,218	105,823
Opossum	1,402	13,736	15,139
Rabbit	2,538	40,837	43,375
Raccoon	985	22,645	23,630
Hudson Seal	1,434	49,829	51,263
Northern Seal	645	34,933	35,578
Skunk	1,493	13,952	15,445
Squirrel	2,576	33,130	35,706

Note: The hair count was taken of both muskrat and Hudson Seal (dyed muskrat), also, of rabbit and Northern Seal (dyed rabbit).

The average diameter of hair tended to be slightly greater in dry-cleaned furs than in the mechanically cleaned furs.

In the mechanically cleaned furs, the average percentage deviation from control indicated a loss in diameter for all under hair except skunk, but the guard hair showed little variation from control.

The average reflection factor of dyed furs was greater in the dry-cleaned than in the mechanically cleaned furs.

The dry-cleaned furs appeared to have lost in pigment after cleaning; the greater proportion of the loss in pigment was evident after the first cleaning.

Six out of nine tests run on the furs were in favor of mechanical cleaning—ether-soluble content, breaking strength, elongation, thickness of pelt, abrasion, and length of hair.   The increase in gloss, diameter and
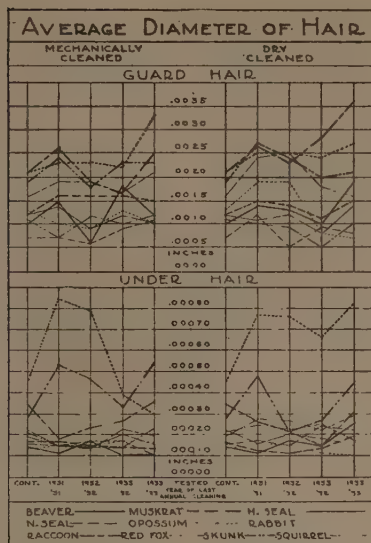
Fig. 3. Average diameter of hair.
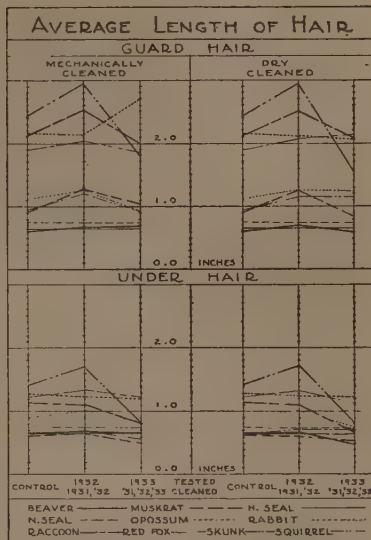
Fig. 4. Average length of hair.
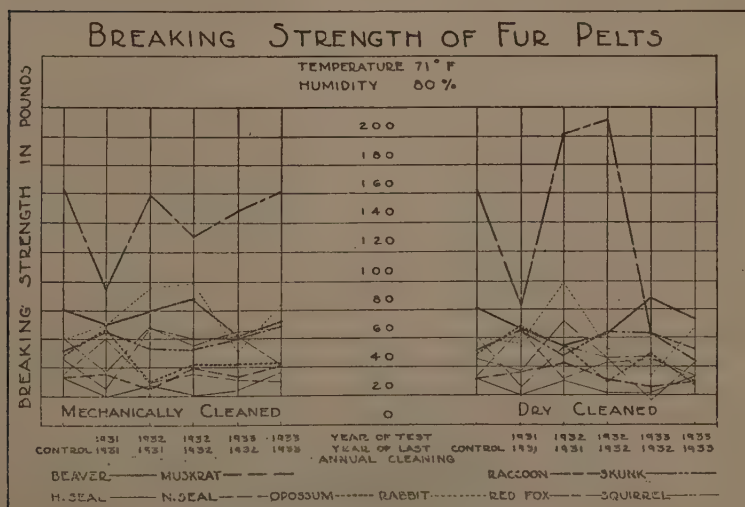
Fig. 5. Breaking strength of fur pelts.
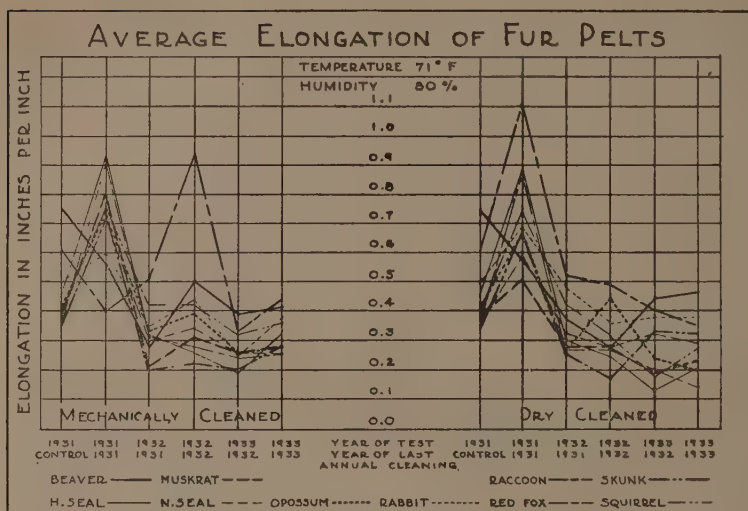
Fig. 6. Average elongation of fur pelts.
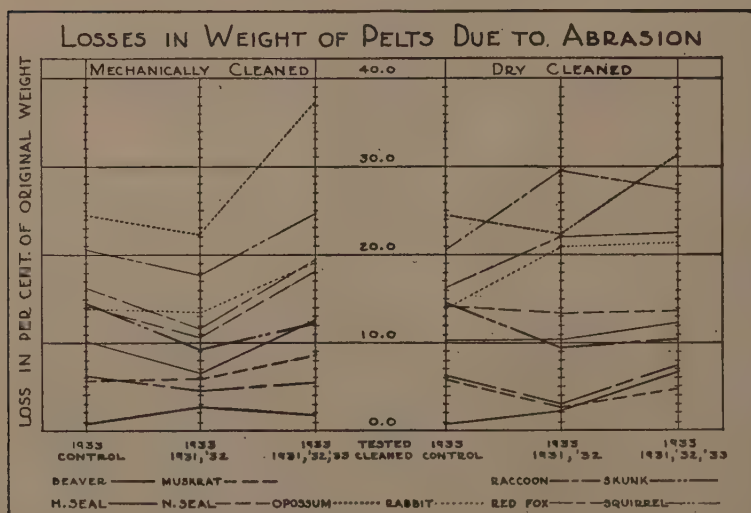
Fig. 7. Loss in weight of fur pelts due to abrasion.

reflection factor averages following dry-cleaning was without doubt caused by the paraffin oil rinse.

Examination of the photomicrographs of the medullas, cross-sections, and scales of hair when compared with the photomicrographs made in previous years show the effect of cleaning upon the hair structure of the furs.

Plates I-IV show photomicrographs of the hair structure of the furs.

1.   The scales of dry-cleaned furs were less pronounced than those of the controls and mechanically cleaned furs. Also, the scales of the under hair were larger than those of the guard hair of the same fur.

2.   The hair having the largest diameter had the smallest scales and the hair having the smallest diameter had the largest scales.

3.   The less durable furs had large medullas and sharp scales. Beaver had the smallest medulla and rabbit the largest medulla, in proportion to the cortex of any of the furs studied.

4.   A definite pattern was found in the medulla of each kind of fur.

5.   The photomicrographs of clipped furs which were dyed showed that the dye penetrates the medulla as well as the cortex.

Hausman's experiments on fur confirm conclusions 2, 3, and 4 in relation to the hair structure of the furs.

SUMMARY OF TESTS MADE

The furs, Hudson Seal, Northern Seal, opossum, skunk, muskrat, beaver, squirrel, rabbit, fox and raccoon, were tested for ether-soluble content, breaking strength and elasticity, shrinkage, color reflection, diameter of hair, gloss, number of hairs to the square inch, length of hair, loss in weight from abrasion; and a microscopic study was made of the hair of the control and cleaned furs.

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EXPLANATION OF PLATES

Note: Photographs of longitudinal and cross section of medulla of the cleaned furs, also of the scales of the mechanically cleaned furs are not given since the structure of the hair showed no appreciable change.

PLATE I

Fig. 1. Beaver.

Fig. 2. Red fox.

1A. Longitudinal section of medulla of guard hair of control. Magnification 500X.

2A. Cross section of medulla of guard hair of control. Magnification 250X.

1B. Longitudinal section of medulla of under hair of control. Magnification 500 X.

2B. Cross section of medulla of under hair of control. Magnification 250X.

1C. Scales of guard hair of control.

2C. Scales of guard hair after dry-cleaning.

1D. Scales of under hair of control.

2D. Scales of under hair after dry-cleaning.
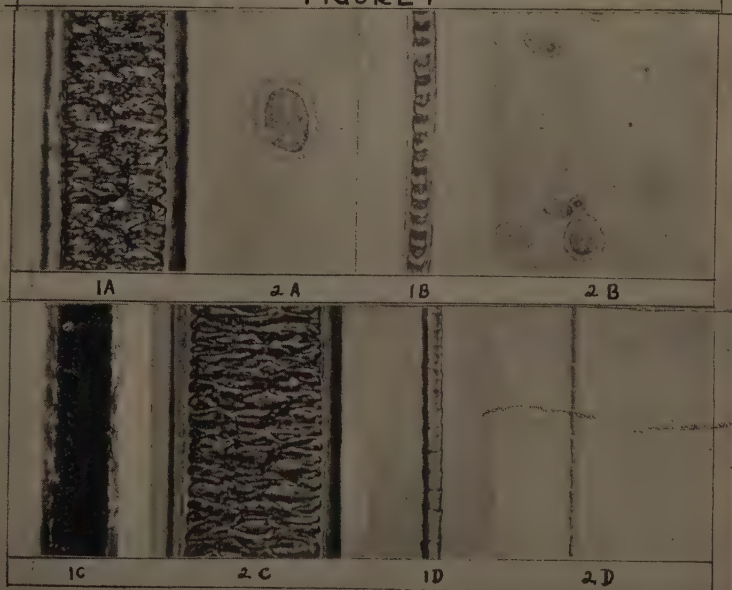
FIGURE 1

FIGURE 2

PLATE II

Fig. 1.   Muskrat.

Fig. 2.   Opossum.

1A.   Longitudinal section of medulla of guard hair of control.
       Magnification 500X.

2A.   Cross section of medulla of guard hair of control.
       Magnification 250X.

1B.   Longitudinal section of medulla of under hair of control.
       Magnification 500X.

2B.   Cross section of medulla of underhair of control.
       Magnification 250X.

1C.   Scales of guard hair of control.

2C.   Scales of guard hair after dry-cleaning.

1D.   Scales of under hair of control.

2D.   Scales of under hair after dry-cleaning.
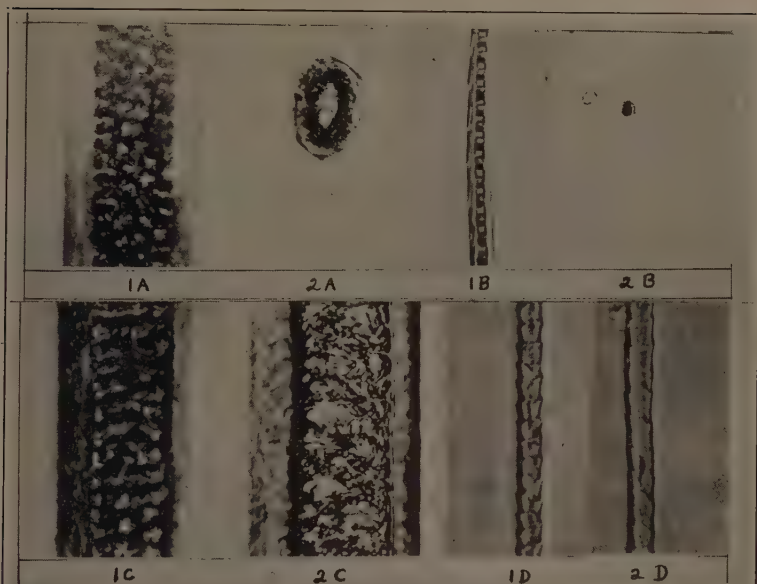
FIGURE 1

FIGURE 2

PLATE III

Fig. 1. Rabbit.

Fig. 2. Raccoon.

1A. Longitudinal section of medulla of guard hair of control.
      Magnification 500X.

2A. Cross section of medulla of guard hair of control.
      Magnification 250X.

1B. Longitudinal section of medulla of under hair of control.
      Magnification 500X.

2B. Cross section of medulla of under hair of control.
      Magnification 250X.

1C. Scales of guard hair of control.

2C. Scales of guard hair after dry-cleaning.

1D. Scales of under hair of control.

2D. Scales of under hair after dry-cleaning.
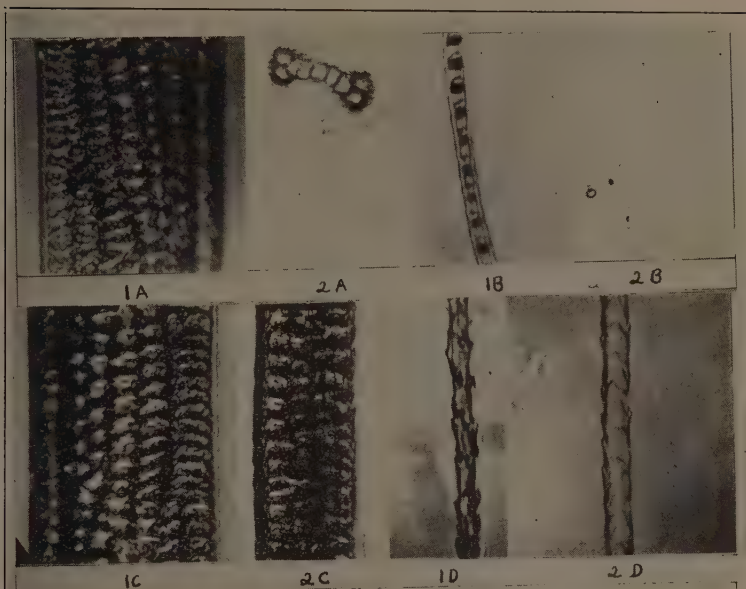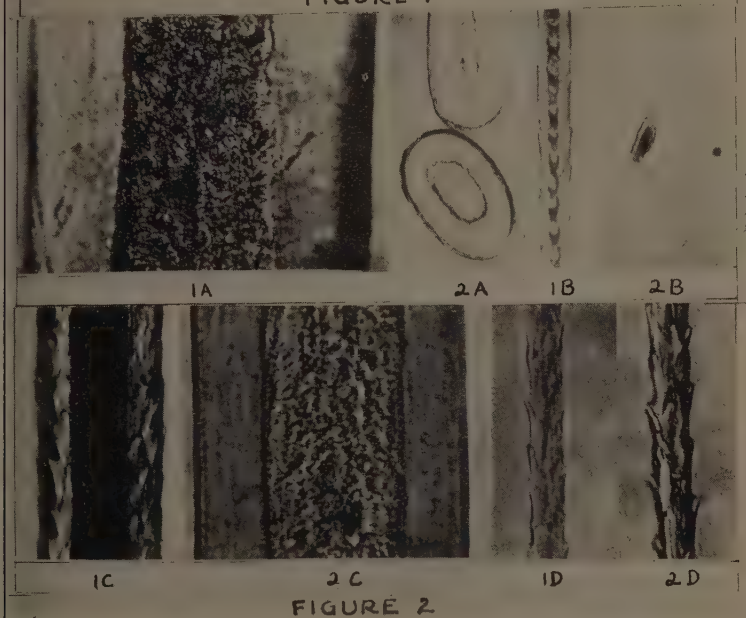
FIGURE 1

FIGURE 2

PLATE IV

Fig. 1.   Hudson Seal.

Fig. 2.   Northern Seal.

1A.   Longitudinal section of medulla of guard hair of control.
       Magnification 500X.

2A.   Cross section of medulla of guard hair of control.
       Magnification 250X.

1B.   Longitudinal section of medulla of under hair of control.
       Magnification 500X.

2B.   Cross section of medulla of under hair of control.
       Magnification 250X.

1C.   Scales of guard hair of control.

2C.   Scales of guard hair after dry-cleaning.

2D.   Scales of under hair after dry-cleaning.

2D.   Scales of under hair after dry-cleaning.

IA   2A   IB   2B

IC   2C   ID   2D

FIGURE 1

IA   2A   IB   2B

IC   2C   ID   2D
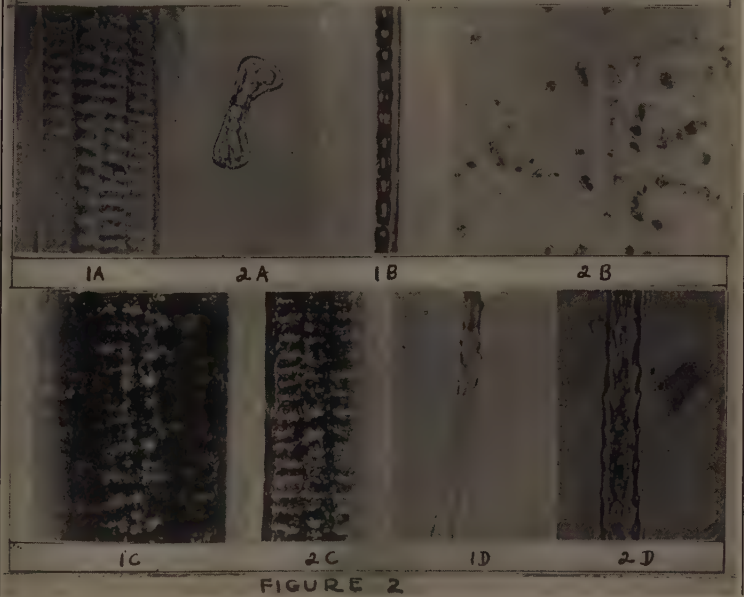
FIGURE 2

PLATE V

Fig. 1. Skunk.

Fig. 2. Squirrel.

1A. Longitudinal section of medulla of guard hair of control.
      Magnification 500X.

2A. Cross section of medulla of guard hair of control.
      Magnification 250X.

1B. Longitudinal section of medulla of under hair of control.
      Magnification 500X.

2B. Cross section of medulla of under hair of control.
      Magnification 250X.

1C. Scales of guard hair of control.

2C. Scales of guard hair after dry-cleaning.

1D. Scales of under hair of control.

2D. Scales of under hair after dry-cleaning.

FIGURE 1

FIGURE 2
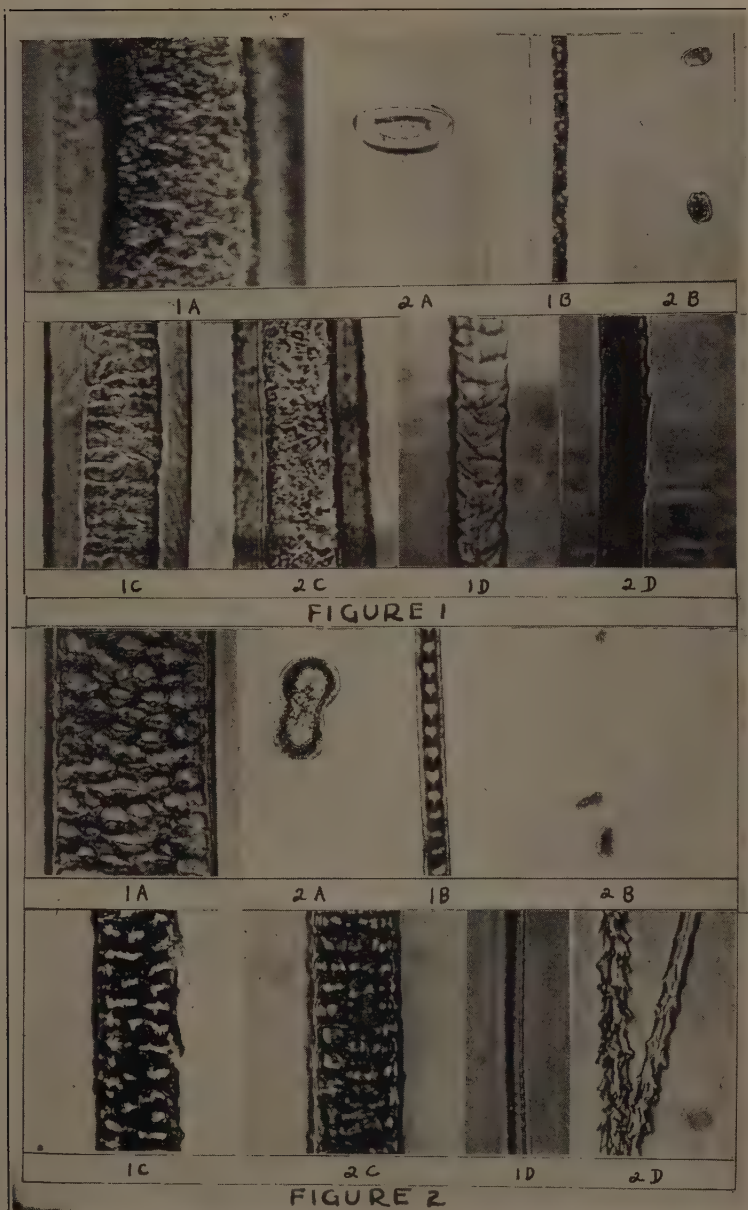
THE PLASMODESMS IN THE LEAVES AND STEMS OF SOME ANGIOSPERMS

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The investigations herein reported were undertaken to ascertain the prevalence and nature of the plasmodesms[1] in the leaves and stems of a number of our common plants, and with the further object of securing some information relative to the functioning of the plasmodesms in the inter-cellular conduction of stimuli, plant foods, viruses, and various substances, even including disease-producing organisms or agents.

In the Cell Theory, as announced by Schleiden and Schwann (1838), multicellular organisms are regarded as aggregates of morphologically separate, independent cells. This conception, with some modifications, still maintains a prominent place in biology, notwithstanding its criticism by Sachs, De Bary, Strasburger, and other able proponents of the Organismal Theory. In contrast to the Cell Theory, the Organismal Theory, as stated by Sachs (Vorlesungen uber Pflanzen physiologie, p. 102), holds that the multicellular organism, however highly organized, is fundamentally a protoplasmic body consisting of a connected whole which is externally clothed by a cell membrane and internally traversed by innumerable transverse and longitudinal walls.

One of the strongest supports of the conception that the protoplasm in multicellular organisms is a connected whole is the presence of connective-like structures between adjacent protoplasts, a feature that has been noted by a large number of investigators and in many species of plants. That these connective-like structures are protoplasmic, and that they are generally continuous, thus establishing a continuity between adjacent protoplasts, have not, however, been fully substantiated and by some authors have been considerably discredited. In as much as their universal presence between the cells of the various living tissues has not been thoroughly established and their continuity is questioned, the plasmodesms can not be evaluated as to their place in the protoplasmic system of multicellular organisms.

Two general types of these apparent connections have been recognized; the relatively large ones, such as those in the sieve tubes and laticiferous vessels of seed plants, and in some species of the red algae; and the fine strands, called Plasmodesmen by Strasburger, which usually require special methods for their detection, a feature that may be responsible for a lack of appreciation of their importance. While the larger connections are regarded as quite limited in occurrence, the plasmodesms have been observed in nearly all living tissues throughout the large groups of plants. Owing

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[1] The use of *plasmodesms* instead of *plasmodesmen* is according to Sharp's "Introduction to Cytology." 3rd ed. 1934. McGraw-Hill, New York.

to their wide occurrence the plasmodesms are of greater significance than the large connections in relation to the protoplasmic continuity of multicellular organisms. The establishment of their universality in living plant tissues and the fact that they are protoplasmic continuities functioning as passageways between adjacent protoplasts, as Sachs, Kienitz-Gerloff (8,9), Gardiner (2,3), Strasburger (12), and some other prominent authorities have maintained, not only would facilitate the explanation of the spread of solutes, viruses, stimuli, and probably disease-producing organisms through tissues, but would account also for the cooperative activities of tissues, such as occur in many of the ordinary physiological processes of plants and in the formation of graft unions and in all other phenomena where the plant functions more or less as a unit.

From the date of Tangl's (13) report in 1879 (claimed to be the first account of plasmodesms) till 1902, plasmodesms attracted the attention of many investigators. Their work disclosed the presence of plasmodesms in the algae, fungi, liverworts, mosses, ferns, Gymnosperms, and Angiosperms.

METHODS AND MATERIALS

The plants included in this investigation were mainly common economic plants, many of which are subject to virus disturbances. Monocotyledons and dicotyledons—both woody and herbaceous types—were represented. The particular plants included were the Irish potato, tomato, pepper, egg plant, nasturtium, watermelon, cucumber, field pumpkin, hubbard squash, onion, regal lily, corn, one species of aster, several varieties of apples, shagbark hickory, and white oak.

Owing to the disclosure that the method of demonstrating the presence of plasmodesms in the leaves and stems did not work so satisfactorily when applied to the tissues of roots, the investigations here reported have been confined to the stems and leaves.

All the preparations were made from fresh material. For the study of plasmodesms in epidermal tissues, mounts of portions stripped from the leaves and stems sufficed. All sections were made free-hand with the aid of a binocular. Satisfactory sections were limited to one cell in thickness.

The satisfactory demonstration of plasmodesms entails (a) the killing of the protoplasts to prevent excessive shrinking during ensuing treatments, (b) the hydration of the cell walls in order to increase their transparency and separate the protoplasts that the plasmodesms may be more visible, and (c) the staining of the protoplasts and plasmodesms without staining the cell walls. In regard to the killing solutions, hydrating reagents, and stains, many different successful methods have been employed of which Tunmann (14) gives a good summary. The reagents which have been used most commonly are: iodine for a killing reagent, as it also assists in the staining of the plasmodesms; chlor-zinc-iodide or sulfuric acid for hydrating the walls; and pyoktanin, methyl violet, gentian violet, haematoxylin or safranin as a staining reagent.

A comparison of the results obtained by the various methods given in Tunmann's Pflanzenmikrochemie, lead to the selection of a modification of Myer's method in which iodine was used for killing and mordanting the tissues, sulfuric acid for hydrating the walls, and pyoktanin for staining the plasmodesms and protoplasts. The sections were placed in a water

solution of iodine two or three minutes, then in 25, 50, and 72 per cent sulfuric acid, remaining only a few minutes in each. Since the rate of action of the acid depends much upon the character of the tissues, a number of trials often were required to determine the proper concentration of acid to use and the time it should be allowed to act. When the hydration was considered sufficient, as indicated by the dark blue to black color of the preparations, the acid was removed by filter paper and pyoktanin then applied and allowed to act five to 10 minutes, after which the preparations were thoroughly rinsed in water and in acetic or weak sulfuric acid when the excess stain was difficult to remove. The chief object of the destaining was to secure a transparency of cell walls. The preparations were finally mounted in 50 per cent glycerine. The pyoktanin used was a freshly made saturated water solution.

While the swelling of the walls accompanying their hydration contributed much to the visibility of the plasmodesms, it resulted in a stretching of the plasmodesms which probably in some instances altered their diameter considerably; and when it was carried far the plasmodesms were broken by the tension as may be seen in a number of the illustrations. No effort was made to ascertain quantitatively how much the plasmodesms were altered by the swelling of the walls. However, in those preparations where different amounts of swelling were obtained, no marked difference in size of plasmodesms traversing walls differently swollen was noted.

PLASMODESMS IN LEAVES

In the leaves the plasmodesms were most easily observed in the epidermal tissue, owing in part to the relative ease with which preparations of suitable thickness could be obtained, and in part to the size of the plasmodesms, some of which were 60 or more microns in diameter in the swollen condition of the tissues of the preparations. The plasmodesms in the mesophyl of leaves were delicate, and for their detection thin transverse sections of fresh material were required. The demonstration of their presence, especially between the palisade cells and between the epidermal and mesophyl cells, was rather difficult and consequently was confined to a few of the species included. Where preparations failed to show the presence of plasmodesms between some of the cells in the mesophyl, the unfavorable orientation and differences in staining reactions of the plasmodesms between different cells were perhaps responsible.

Between the elongated rectangular epidermal cells, such as are characteristic of grass leaves and are common in the region of the veins of most leaves, two types of plasmodesms were noted. Those traversing the end walls were numerous, fine, and in their size, regular arrangement, and in the barrel-shape figure they formed resembled the fibers in mitosis (fig. 8), whereas those traversing the side-walls commonly occurred singly or in small groups, varied in diameter from a few to 60 or more microns and were irregularly distributed (figs. 2, 3, 4, 8). In the leaves of some plants, as those of corn (fig. 4), the lateral connections were relatively numerous, whereas in the leaves of some other plants, as illustrated by the onion (fig. 2), they were comparatively sparse. Similar variations were found in *Viscum album* by Kuhla (11) who reported a variation ranging from 26 to 46 in the number of lateral plasmodesms between the epidermal cells of the leaf.

The plasmodesms between the irregularly shaped epidermal cells, although varying considerably in size and arrangement, were of one type (figs. 1, 5, 6) and resembled the lateral connections between the rectangular epidermal cells. In a surface view they appeared relatively numerous and pretty well distributed through all the transverse walls, except those bordering the guard cells, where, according to the casual observations, they were more delicate, fewer in number and larger, or lacking, all these situations sometimes occurring in the same preparation. A more careful study, however, would likely have disclosed- that the plasmodesms are constantly present between the guard cells and adjacent epidermal cells though quite variable in type, at least for different species of plants. Such a disclosure would be in accord with the observations of both Kohl (10) and Kuhla (11) who reported the presence of plasmodesms between the guard cells and adjacent epidermal cells as a constant feature in *Viscum album*.

In general the plasmodesms in the epidermal cells of the leaves and in all the tissues having thin cellulose walls in both leaves and stems were observed to traverse the walls as undivided strands throughout their length. They were the solitary type according to Kuhla's (11) classification, which designates those undivided in their course as solitary plasmodesms, whereas those divided into fine strands in a part of their course are designated as the aggregate type.

It was relatively easy to demonstrate in thin longitudinal sections of veins a system of plasmodesms establishing connections between the epidermal cells and the tissues of the veins and between the different tissues of the veins. In the leaves of the potato, onion, and aster, where special effort was made to demonstrate their presence in the mesophyl, plasmodesms were found connecting the epidermal cells with the palisade and spongy parenchyma. Those plasmodesms establishing connections between the palisade cells and epidermal cells were delicate and sparse while those between the palisade cells in the preparations observed were delicate but relatively numerous. These observations are in part out of accord with Kuhla's (11) report that in the leaves of *Visrum album* the plasmodesms between the epidermal and palisade cells were notably large. Those observed between the spongy cells were quite variable in size, some being delicate and others relatively large (fig. 7).

THE PLASMODESMS IN STEMS

IN THE PRIMARY MERISTEM

Since the primary tissues of stems, such as those constituting the first formed epidermis, cortex, phloem, cambium, xylem, and rays, are immediate products of the primary meristems, the presence of plasmodesms in the primary meristems was of special interest. In the stem tips of both the herbaceous and woody stems, the presence of plasmodesms was easily demonstrated (figs. 9, 10, 11), thus disclosing that the stem tissues were formed from cells between which there was already a well-established system of plasmodesms. This raises the question as to the history of the plasmodesms in connection with the processes of differentiation that transform the cells from the meristem into the various types of tissues. The plasmodesms of the tip meristems in all the stems observed were comparatively uniform in the various aspects. Between some cells they were fine and numerous, re-

sembling the system of fibers in mitosis while those radiating from the same cells in other directions were often few but comparatively large (figs. 10 and 11). In the tip meristems observed in the herbaceous stems most, if not all, of the plasmodesms were of the solitary type; whereas in the tip meristems of woody stems it was noted, especially in the basal region of the meristems, that some of the large plasmodesms were divided into fine strands near midway of their course. This feature was found to be most pronounced in meristems in winter dormancy (fig. 11).

IN THE TISSUES OF THE OLDER REGIONS OF STEMS

Between the epidermal and sub-epidermal cells of stems the presence of plasmodesms was readily demonstrated and between the cells of the cortex the plasmodesms were especially pronounced (figs. 13-18). Thus the epidermal cells were found to communicate laterally with each other and internally with the cortex. The cells of the cortex were connected in all directions by plasmodesms. In preparations, such as those made from lengthwise radial sections, which are specially favorable for showing the plasmodesms through the tangential and transverse walls, it was possible to trace an uninterrupted series of plasmodesms from epidermis through the cortex and even into the xylem when sections of suitable extent and thickness could be made. Where bark was present they were traceable only from the cork cambium. The observations as to their presence in cork tissue were rather casual; but, if present, they were either less conspicuous than those of the cells beneath or required different methods to make them visible.

In both radial and tangential lengthwise sections, in which views the cells of stems, except those of the rays, are generally rectangular and usually much elongated in the direction of the axis of the stem, two rather distinct types of plasmodesms were observed (fig. 14). Those traversing the end or transverse walls were numerous, fine, and regularly arranged. They resembled the fibers in mitosis. Those transversing the lateral walls were irregularly distributed, quite variable in size, and much less numerous per unit area of wall surface than those traversing the end walls. They were either single or in small groups. In size they ranged from a few to 65 microns in diameter. In stems, especially in herbaceous ones, the plasmodesms were similar as to types and general features to those previously described between the rectangular cells in surface views of the epidermal tissues of leaves and stems. In woody stems where the walls were thickened the lateral plasmodesms were commonly of the aggregate type, being divided into delicate strands, variable in number, in the region of the middle lamella (fig. 14). Also when the walls in herbaceous stems were considerably thickened, as, for example, in the flowering stalk of the onion, the lateral plasmodesms were similarly divided into fine strands through the region of the middle lamella. Apparently this feature of the plasmodesms is associated with wall thickening and does not depend upon the species or the type of plant.

In the rays, especially in woody stems, the plasmodesms were exceptionally pronounced (fig. 19). They were present not only between adjacent ray cells but between ray cells and adjacent parenchyma cells of the xylem and phloem running lengthwise of the stem (fig. 20). It was

thus possible in stems to trace a system of plasmodesms which had its origin in the primary meristem and had so developed during subsequent growth as apparently to maintain connections between all the living cells. The origin of the plasmodesms in the meristems and their establishment of a complete system of connections between the living cells have been previously described in a number of Angiosperms by Kienitz-Gerloff (8, 9), Kuhla (11), Strasburger (12), Gardiner (2, 3), and others and in *Pinus sylvestris* and allied species by Gardiner (3) and Hill (4). This, of course, does not establish the fact that such a system of connections consists of protoplasmic continuities at all points in its course, thus maintaining as a whole the protoplasm of the entire stem, as has been the belief of a number of authorities. There still remains the task of establishing the protoplasmic nature and continuity of the plasmodesms.

In those herbaceous stems where the plasmodesms were single throughout their course, the evidence was much in favor of the theory of protoplasmic continuity, for the plasma membranes and contents of the plasmodesms appeared as continuations of the protoplasts. There were no indications of interruptions between the protoplasts they connected (fig. 3). In cases where the plasmodesms are divided into fine threads during a part of their course, like those characteristic of thick walls, there was no evidence of a discontinuity between the plasmodesms and the protoplasts (fig. 12). The question of continuity here pertains to the fine strands whose continuity was difficult to trace. Mention should be made here of recent articles by Jungers (6, 7) who is inclined to regard plasmodesms as structures of the cell wall and therefore not protoplasmic. His conclusions were based on studies of plasmodesms in endosperms, sieve calluses, and in some of the red algae. It seems that if his idea is correct there should be recognizable breaks or lines of juncture between the plasmodesms and the protoplasts, and such was not the case in the material observed in this investigation. In the plasmodesms that are divided into delicate strands in the region of the middle lamella, as those characteristic of thick walls, the junctures in the fine strands may easily escape detection. However, in the onion, apple, and spruce, where effort was made to decide this question, the evidence favored the view that the continuity was maintained throughout the entire length of the plasmodesms.

A number of functions, such as the conduction of stimuli, enzymes, and various types of substances, have been ascribed to the plasmodesms. Judged upon their prevalence, apparent size and continuity, the simple plasmodesms, which were found to be characteristic of the herbaceous plants and of tissues with thin walls in general are capable of affording passage ways not only for stimuli and solutions, but for bodies many times the size of most disease-producing agents or organisms. In case of the aggregate type of plasmodesms the fine strands were commonly visible under the ordinary high-power combinations of the microscope. Their size would therefore permit the passage of small micro-organisms, and in the conduction of solutions their number may compensate for their lack in size.

The fact of the apparent ever-presence of the plasmodesms between the cells in the primary meristems and throughout the subsequently formed tissues of the stems and leaves, suggests that they have a place of importance in the protoplasmic organization of the plant. Strasburger (12) noted that plasmodesms were formed between stock and scion of grafts in the

apple, spruce, and fir and considered that they have an important bearing in the establishment of good unions. Buder (1) and Hume (5) have contributed support to Strasburger's contention, and the prevalence, structural features, and history of the plasmodesms disclosed in this article strongly favor it.

SUMMARY

The investigation pertains to the prevalence and nature of the plasmodesms in the leaves and stems of the Irish potato, tomato, pepper, egg plant, nasturtium, watermelon, cucumber, field pumpkin, hubbard squash, onion, regal lily, corn, one species of aster, several varieties of apples, shagbark hickory, and white oak.

A satisfactory procedure for making the plasmodesms visible in leaves and stems consisted of killing the material in iodine, hydrating the walls in sulfuric acid, and staining the protoplasts and plasmodesms with pyoktanin.

In all the plants included in the observations, plasmodesms were present in all the living tissues examined and apparently between all the living cells of the leaves and stems.

The plasmodesms were of two general types; those traversing the walls as single strands, and those divided into finer strands in a part of their course. The type consisting of a single strand was characteristic of leaves, herbaceous stems, and in general of tissues with thin walls, whereas the second type of plasmodesms was characteristic of tissues with thick walls and hence of woody stems. Between the elongated rectangular cells of herbaceous tissues there were usually two kinds of the simple or solitary type of plasmodesms. Those traversing the end walls were numerous, fine, evenly spaced, uniform in size, and formed barrel-shaped figures resembling those of the spindle fibers in mitosis, whereas those traversing the side walls were irregularly distributed, varied in size from a few to 65 or more microns in diameter and were commonly single but often in small groups.

In the simple type of plasmodesms the evidence of continuity was quite convincing, as no discontinuity in plasma membrane or in protoplasmic contents was detectable anywhere in the course of the plasmodesms. In the other type of plasmodesms, where there was a division into fine strands that traverse the closing membrane of the pit, it was difficult to decide whether or not the fine strands were continuous. In the onion, spruce, and apple, however, by special effort it was possible to so trace the fine strands so as to convince one of their continuity.

The plasmodesms were found present in all the primary meristems of stems. Thus all the tissues arising therefrom, as those of stems, leaves, and flowers, are products of cells primarily characterized by the presence of plasmodesms. It was possible to trace a continuous series of plasmodesms which had its origin in the primary meristems and embraced all subsequent tissues arising therefrom. In herbaceous plants where it was evident that the plasmodesms maintain a continuity of protoplasm, their prevalence supports the Organismal Theory. Owing to their prevalence and size throughout their entire course in leaves and stems of herbaceous plants and in the thin-wall tissues in all plants, it is quite believable that plasmodesms function in the conduction of viruses, organisms, plant foods, and

various other types of substances. In tissues with thick walls, such as are characteristic of woody plants, the adaptability of the plasmodesms to conduct is less apparent because so many of them are divided into fine strands whose continuity is not obvious, and whose capacity to conduct is apparently small. Nevertheless, if continuous, the fine strands are large enough to permit small disease-producing organisms or agents to pass, and their number may compensate for their lack in size in their conduction of solutions.

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PLATE I

EXPLANATION OF FIGURES

The plasmodesms in all the following figures are the dark strands be-
tween the dark bodies which are the protoplasts.   The stem sections are
all lengthwise radial.

Fig. 1.   Surface view of some epidermal cells of an Irish potato leaf, showing
the plasmodesms; x 450.

Fig. 2.   Surface view of some rectangular leaf cells of an onion leaf showing
variation in size and the sparseness of the plasmodesms; x 450.

Fig. 3.   Surface view of some rectangular leaf cells of an aster between which
the plasmodesms are rather numerous, and vary in size from a few to as many as
40 microns in diameter; x 450.

Fig. 4.   Surface view of the epidermis of a corn leaf showing the plasmodesms
rather numerous and quite variable in size; x 450.

Fig. 5.   Surface view of some cells of a pepper leaf showing the plasmodesms;
x 450.

Fig. 6.   Surface view of a number of cells of a pepper leaf giving a more
comprehensive view of the number and distribution of the plasmodesms; x 200.

Fig. 7.   Some spongy cells of a pepper leaf showing at the point of the arrow
the delicate connections common between the spongy cells of leaves; x 800.

Fig. 8.   A rectangular epidermal cell from a leaf of the Irish potato showing
the large lateral connections and at the ends of the arrows the fine plasmodesms that
resemble the fibers in mitosis; x 800.

Fig. 9.   A general view of the plasmodesms in the meristem of an apple twig;
x 200.

Fig. 10.   Enlarged view of some cells from the meristematic tip of an apple
twig showing prevalence and variability of the plasmodesms; x 450.

Fig. 11.   Some cells from the base of a meristematic tip of an apple twig show-
ing the plasmodesms a little better differentiated into large scattered lateral ones
and the fine, numerous end ones; x 450.

Fig. 12.   An enlarged single plasmodesm showing its continuity with the proto-
plasts at each end; x 800.

Fig. 13.   Section through the cortex of an apple twig showing the plasmodesms;
x 320.

Fig. 14.   A section through the cortex of an apple twig where the cells were
elongated rectangles, showing the large lateral connections, many of which are
divided into fine strands through the region of the middle lamella and the fine
plasmodesms through end walls; x 600.

Fig. 15.   Plasmodesms in the cortex of the stem of an Irish potato; x 450.

Fig. 16.   Plasmodesms in the cortex of a Norway spruce; x 200.

Fig. 17.   Plasmodesms in the cortex of the stem of a tomato; x 320.

Fig. 18.   Plasmodesms in the cortex of the common elder; x 200.

Fig. 19.   Plasmodesms between the ray cells of an apple twig; x 320.

Fig. 20.   Radial lengthwise section of an apple twig showing the plasmodesms be-
tween a ray cell and adjacent parenchyma cells at right angles to the ray cells; x 320.

PLATE I

REDESCRIPTIONS OF NORTH AMERICAN SMINTHURIDAE

J. W. FOLSOM[1]

From the Bureau of Entomology, United States Department of Agriculture

The purpose of this article is to redescribe some of the Sminthuridae that were named years ago by Ryder, Fitch, Packard, MacGillivray, Harvey, and Folsom.

No attempt has been made to resurrect doubtful species. In fact, fifteen of the nineteen species included in this paper have been redescribed and figured from cotypes. The remaining four are common species whose coloration and habits are so distinctive as to leave no doubt concerning their identity.

Packard's cotypes described in his Essex County article (1873) are in the Museum of Comparative Zoölogy, at Cambridge, Massachusetts. I made descriptions and drawings of all these cotypes (through the courtesy of Mr. Samuel Henshaw) while living in Cambridge, and was able also to collect most of the Massachusetts species of Collembola described by Packard.

The Essex County paper has no figures; nevertheless Packard made many pencil sketches as he studied his material under low powers of a compound microscope, and these sketches, which he gave to me, have often aided in the identification of his species.

Neither did MacGillivray give figures of any of his species, but he gave me cotypes of almost all the species that he had described. In addition to these, I have studied (through the courtesy of Prof. C. R. Crosby) such of MacGillivray's material as is now in the Cornell University collection.

For several years, Prof. F. L. Harvey frequently exchanged specimens with me, and I eventually acquired Harvey's collection of Collembola.

I also once described species of Sminthuridae without the necessary illustrations; these are given here, and the original descriptions have been improved.

Sminthurinus remotus (Folsom)

Plate III, fig. 9-12

Smynthurus remotus Folsom, 1896 d.

Bluish black. Body dorsally segmented; sides with several rows of pale round spots. Ventral tube black. Head mostly black; oral region pale. Eye spots black, broadly surrounded with yellow, especially on the vertex. Ant. 1 black; 2 and 3 yellow; 4 blackish purple. Legs yellow, black basally, including the bases of the femora. Manubrium black basally, unpigmented apically; dentes unpigmented. Eyes (Fig. 9) 8+8, the inner one smaller. Antennae short, one-fifth longer than the head, with segments about as 14: 27: 35: 62; ant. 4 not subsegmented. Proximal tubercle of ant. 3 simple (Fig. 10). Ungues of fore feet three-fourths longer than those of hind feet. Unguis (Fig. 11) without inner teeth. Unguiculus untoothed. Tenent

hairs 2. Mucrones (Fig. 12) one-third to one-half as long as dentes, with both dorsal margins usually entire, rarely with a few minute teeth near the base only. Anterior lobe of tenaculum with two setae. Dorsum of body with scattered minute setae posteriorly; a bothriotrix is present on the genital segment antero-laterally. Integument minutely tuberculate. Maximum length, 0.75 mm.

The cotypes occurred under logs in a peat bog.

Massachusetts: Belmont, May 3, 5, 25, J. W. F.

Sminthurinus minutus (MacGillivray)

Plate III, fig. 13-18; Plate IV, fig. 19, 20

Smynthurus minutus MacGillivray, 1894; Mills, 1930b.
Sminthurus minutus Guthrie, 1903; Folsom, 1928.

Black and yellow. Body black dorsally; genital and anal segments yellow except dorsally. Sternum mostly black. Head mostly yellow; dorsally yellow between the eyes and black behind them; just below each eye spot are usually three round equal clear spots in longitudinal alignment. Thoracic segments and abd. 1 are demarcated by transverse lines. Antennae and legs yellow. Furcula unpigmented or pale yellow. Eyes (Fig. 13) 8+8, the inner eye small. Median ocellus present. Antennae two-fifths longer than the head; ant. 4 not annulate. Distal sense organ of ant. 3 as in figure 14; proximal tubercle of ant. 3 simple (Fig. 15). Unguis (Fig. 16) stout, with one inner tooth (sometimes absent) and an outer tooth. Unguiculus (Fig. 16) broad, with an inner tooth (obscure or absent on the fore feet) and a subapical seta. Mucro (Fig. 17) one-half as long as dens; outer margin entire, inner margin with about 20 rounded teeth. Rami of tenaculum (Fig. 18) tridentate, with a basal papilla; anterior lobe with two setae. Subanal appendages of female (Fig. 19,20) two-fifths as long as mucro, palmately branched. Body setae short, curving, simple. Integument minutely tuberculate. Length, male, 0.55 mm.; female, 0.7 mm.

This redescription is from cotypes given to me by MacGillivray, and from others belonging to the Cornell collection.

S. minutus has thus far been taken only in greenhouses.

New York: Ithaca, R. H. Pettit.

Massachusetts: Cambridge, February 7, J. W. F.

Minnesota: Minneapolis, J. E. Guthrie.

Iowa: Burlington, July, J. E. Guthrie.

Sminthurinus quadrimaculatus (Ryder)

Plate I, fig. 1; Plate IV, fig. 21-27; Plate V, fig. 28-31.

Smynthurus quadrimaculata Ryder, 1879.
Smynthurus quadrimaculatus MacGillivray, 1891, 1894; Mills, 1930b.
Smynthurus 6-maculata Harvey, 1892.
Sminthurus quadrimaculatus Guthrie, 1903; Folsom, 1928.

Body blackish purple with two pairs of large enamel-white subdorsal spots (Fig. 1), the posterior spots larger than the anterior. Sternum purple anteriorly, white posteriorly. Mesothorax defined posteriorly by a groove extending to the bases of the mid legs. Head yellow laterally; vertex with a median black mark, and a white spot between this and each eye spot. Ant. 1 and 2 whitish, tinged with purple; 3 pale proximally, dark purple

distally; 4 dark purple. Precoxae mostly blackish purple; coxae yellow and blackish; trochanters mostly yellow; femora pale yellow; tibiotarsi purple, pale yellow basally. Furcula unpigmented, or manubrium and dentes tinged with purple. Eyes (Fig. 21) 8+8, the inner eye smaller than the others. Median ocellus present. Antennal segments about as 1 : 2 : 3 : 6 ; ant. 4 not subsegmented. Distal sense organ of ant. 3 as in figure 22 ; proximal tubercle of ant. 3 simple (Fig. 23). Unguis (Fig. 24) with three inner teeth, and one pair of distal lateral teeth (Fig. 25) ; pseudonychia serrate, shorter on the fore feet. Unguiculus relatively long (Fig. 24), unidentate, with a short subapical seta; shorter and narrower, with a longer seta, on the fore feet. Tenent hairs usually 5, 5, 5 (occasionally 4 or 3). Manubrium naked ventrally. Dens (Fig. 26, 27) with 8 subapical setae: 6 in a transverse row and one pair anterior to these. Mucro half as long as dens, with both dorsal margins serrate (Fig. 28); teeth about 17-22 on each side. Rami of tenaculum (Fig. 29) tridentate, with a proximal papilla; anterior lobe elongate, with two setae. Subanal appendages of female palmately branched (Fig. 30, 31). Body with sparse minute curving simple setae. Integument minutely tuberculate. Maximum length, 1.3 mm.

I have seen a few individuals in which the two anterior white spots of the body were absent.

The proximal inner tooth of the unguis may be absent.

Ryder's description and figure are sufficient to place this common species. Its markings are distinctive, there being no other known species in our fauna with which it could be confused.

I have studied cotypes of Harvey's 6-*maculata*.

The Mexican form referred to *quadrimaculatus* by Handschin (1928a) is evidently another species. I name it *Sminthurinus handschini*.

S. quadrimaculatus is commonly found under loose decaying bark of trees or logs, often in large colonies. When it inhabits the decaying blackish powder left by bark beetles, it may easily pass unnoticed, on account of its color and small size; but when it moves, and the sunlight is reflected from the white spots, it is easily seen with the naked eye. The species occurs also on fungi and on herbage.

Maine: Orono, July, August, September, F. L. Harvey.

Massachusetts: Arlington, May 1, July 6, 30, September 5, 12, J. W. F.; Waltham, July 29, J. W. F.; Framingham, June 13, C. A. Frost; South Natick, November 7, A. P. Morse; Springfield, June, G. Dimmock.

New York: Ithaca, July 20, A. D. MacGillivray; McLean, May 16, C. R. Crosby; Mendon Ponds, October 14, E. A. Maynard.

Pennsylvania: Philadelphia, J. A. Ryder.

Florida: Gainesville, March 17, T. H. Hubbell.

Illinois: Homer, May 12, 13, June 21, October 11, 13, J. W. F.; Urbana, October 15, 21, J. W. F.; Oakwood, April 20, T. H. Frison.

Iowa: Ames, November 1, H. B. Mills.

Sminthurinus aureus (Lubbock)

Plate V, fig. 32-38; Plate VI, fig. 39-44

Smynthurus aureus Lubbock, 1862, 1873; Uzel, 1890; Mills, 1930b.
Sminthurus aureus Tullberg, 1872; Schött, 1894, 1902; Lie-Pettersen, 1896; Carl, 1899, 1901; Krausbauer, 1902; Guthrie, 1903.

Smynthurus henshawii Folsom, 1896.
Sminthurinus aureus Börner, 1901; Ågren, 1903; Axelson, 1904, 1905; Collinge and Shoebotham, 1910; Linnaniemi, 1907, 1912; Denis, 1921, 1922, 1927, 1931; Stach, 1921, 1922, 1929; Handschin, 1929; Womersley, 1932.

Dark orange; abd. 6 paler. Dorsum dusky in large individuals. Eye spots black, with a large buff spot on the mesal side of each. Median ocellus prseent. Face strongly gibbous above the mouth. Ant. 1 and 2 pale yellow; 3 pale yellow basally, dark purple distally; 4 dark throughout. Legs pale orange. Furcula unpigmented. Eyes (Fig. 32-34) 8+8, two being smaller than the others. Antennae three-tenths longer than the head, with segments about as 1 : 2 : 3 : 6. Proximal tubercle of ant. 3 simple (Fig. 35, 36). Ant. 4 not subsegmented. Unguis (Fig. 37-39) slender, with or without an inner tooth, and without lateral teeth. Unguiculus (Fig. 37) more slender on the fore feet, with a subapical filament exceeding the unguis; untoothed usually. Unguiculi of mid and hind feet broader, with shorter subapical filament and with an inner tooth (Fig. 38, 39). Tenent hairs 4 to 8. Dentes 2.3 to 2.5 times as long as mucrones. Mucro (Fig. 40, 41) with inner margin serrate, sometimes obscurely; outer margin entire, or obscurely toothed proximally. Rami of tenaculum (Fig. 42) tridentate, with a proximal appendage; anterior lobe with two setae (sometimes one). Subanal appendages of female (Fig. 43, 44) of the palmate type. Clothing of sparse short setae. Bothriotricha: 3 on each side of the abdomen; 1 anterolaterally on each side of abd. 5. Integument finely tuberculate. Maximum length, 1.1 mm.

The proximal tubercle of ant. 3 is in some individuals absent, apparently.

In North America, as in Europe, this species is highly variable in coloration, but the color variations have not yet been studied thoroughly in this country.

In 1898 I sent Massachusetts specimens of my S. henshawii to Dr. C. Schäffer, who reported that they differed from *S. aureus* Lubb. only in the very dark color of the last two antennal segments. He gave me European examples of *aureus* for comparison.

S. aureus is common in the soil under dead leaves, logs, boards, stones, etc., and often occurs on temporary pools of rain water. It may be taken throughout the winter.

Massachusetts: Cambridge, February 24, 25, 26, March 14, October 22, J. W. F.; Arlington, January 6, February 21, March 10, April 9, 11, 12, September 5, 25, J. W. F.; Stony Brook, June 12, J. W. F.

Illinois: Homer, February 29, March 1, 2, April 23, 24, 25, 29, J. W. F.; Urbana, April 30, May 9, J. W. F.

Iowa: Ames, March 28, April 6, H. B. Mills; Sioux City, January 17, C. N. Ainslie.

Minnesota: March, April, December, J. E. Guthrie.

Canada: Arnprior, Ontario, January, February, C. Macnamara.

Sminthurinus elegans (*Fitch*)

Plate I, fig. 2; Plate VI, fig. 45-47; Plate VII, fig. 48-51

Smynthurus elegans Fitch, 1863; Packard, 1873; MacGillivray, 1891, 1894.
Sminthurus quadrilineatus Tullberg, 1871, 1872; Schött, 1894; Reuter, 1895; Schäffer, 1896; Poppe and Schäffer, 1897; Scherbakow, 1898; Carpenter and Evans, 1899; Krausbauer, 1902.

Sminthurinus aureus var. *quadrilineata Börner,* 1901; Ägren, 1903; Axelson, 1905; Linnaniemi, 1912; Stach, 1922, 1929; Handschin, 1928a, 1929.
    Sminthurus aureus var. *quadrilineatus* Schött, 1902.
    Sminthurinus elegans, Folsom, 1928; Mills, 1930b.

Body color pale yellow, yellowish green, or green; pigment black. On each side of the body are two irregular black stripes (Fig. 2): a wide lateral stripe continued forward on the gena, and a narrower subdorsal stripe, more or less broken. Along the median dorsal line of the body is an anterior moniliform stripe. Abd. 6 yellow. Head yellow, with a median dark brown stripe between the eyes, separated from the eyes by a white spot on each side. Median ocellus present. Sternum, legs beyond coxae, and furcula white. Ant. 1 and 2 white; ant. 3 and 4 purplish, or ant. 3 white proximally. Eyes (Fig. 45) 8+8, with two much reduced, on each side. The proximal tubercle of ant. 3 is said to be simple; I have not been able to see it yet. Ant. 4 not segmented. Proximal precoxa of mid leg with an anterior elongate rounded lobe (Fig. 46); on hind legs, a hemispherical lobe in a similar position. Unguis (Fig. 47, 48) untoothed as a rule, occasionally with a weak inner tooth. In potassium hydroxide a feeble distal tunica appears (Fig. 48). Unguiculus with a subapical seta exceeding the unguis on the fore feet only. Tenent hairs 3 or 4 (sometimes 5). Mucro (Fig. 49) about half as long as dens; inner margin serrate, the teeth sometimes rounded; outer margin entire, or obscurely toothed proximally. Tenaculum (Fig. 50) stout; rami tridentate, with a basal papilla; anterior lobe with one seta. Anal appendages of female (Fig. 51) with four or five branches. Clothing sparse, short. Integument granulate. Maximum length, 1 mm.

As a variation, the median dorsal moniliform line may be absent.

In some specimens from Ames, Iowa, all four antennal segments are ferruginous, with ant. 4 darker distally. Legs white, with the tibiotarsi and sometimes the femora ferruginous.

Often the body is entirely black, with the legs white (var. *ochropus* Reut.).

This common species, with its distinctive coloration, is evidently the form that Fitch described as *elegans,* especially since we know of no other species that could be confused with it.

In 1898 I sent specimens of elegans to Dr. C. Schäffer, who reported that they were *quadrilineatus* Tull., of which he gave me European examples.

S. elegans is a species of the soil, and often occurs under sticks or logs in grassy places, and on the leaves of herbs.

Maine: Orono, May, F. L. Harvey.

Massachusetts: Cambridge, October 22, J. W. F.; Arlington, April 21, 23, May 1, 2, 3, 5, 10, 13, 27, August 21, J. W. F.; Belmont, May 25, J. W. F.

New York: May, A. Fitch.

Illinois: Homer, April 28, 29, 30, May 11, 14, June 3, 6, J. W. F.

Iowa: Ames, November 1, H. B. Wells.

Tennessee: Knoxville, J. Curtis.

Washington: Yakima, August 23, October 22, A. R. Rolfs.

Bourletiella arvalis (*Fitch*)

Plate VII, fig. 52-56; Plate VIII, fig. 57, 58

Smynthurus arvalis Fitch, 1863; Packard, 1873; MacGillivray, 1891, 1894.
Smynthurus luteus Lubbock, 1968, 1873.
Sminthurus fulvus Lie-Pettersen, 1896, 1898.
Sminthurus luteus Schäffer, 1896, 1900; Carpenter and Evans, 1899; Börner, 1901; Krausbauer, 1902; Ågren, 1903.
Bourletiella lutea Collinge and Shoebotham, 1910; Linnaniemi, 1912; Bartholin, 1916; Brown, 1918; Handschin, 1919, 1924, 1928b, 1929; Wahlgren, 1919; Stach, 1922, 1929; Denis, 1931.
Bourletiella arvalis Folsom, 1928; Womersley, 1932.

Yellow; sternum white; eye spots large and black. Ant. 1 and 2 pale; 3 and 4 purple, or 3 pale proximally. Legs pale yellow. Furcula unpigmented, or pale yellow basally. Eyes (Fig. 52) 8+8, the inner eye reduced. Antennal ratio about as 2 : 3 : 6 : 9. Ant. 4 six or seven-segmented, with 4 or 5 intermediate subsegments (Fig. 53). Ant. 3 organ as in figure 54. Claws alike on all feet. Unguis (Fig. 55) broad, feebly curving, with a pair of lateral teeth and an evident tooth near the middle of the inner margin. Unguiculus with a short subapical seta. Tenent hairs usually 3. Dens about two and one-half times mucro. Mucro (Fig. 56) with entire margins. Rami of tenaculum (Fig. 57) tridentate; anterior lobe relatively large, with two setae (rarely three). Anal appendages of female as in figure 58; minutely fringed apically. The anal segment of the male bears a median dorsal crest between five strong hooks, all of which point backward. On each side of the crest are two similar hooks, one in front of the other. Just behind the crest is a more slender median hook. Body setae mostly short and curving. Integument granulate. Length, 1.2 mm.

As variations, the inner tooth of the unguis may be absent, and only two tenent hairs may be present.

European examples of *luteus* Lubb. agree accurately with North America specimens of *arvalis* Fitch, as I learned by an exchange of material with Dr. C. Schäffer.

B. arvalis is common and often abundant in grasslands, clover fields, truck gardens, on herbage and on trees. Both Fitch and Lubbock have described the peculiar playful antics of this species.

Massachusetts: Boston, August 11, J. W. F.; Cambridge, May 23, June 11, J. W. F.; Arlington, May 3, 12, 14, 20, 23, 27, 31, July 10, 12, 18, 27, September 5, 25, J. W. F.; Belmont, May 25, J. W. F.; Stony Brook, July 16, J. W. F.; Dedham, August 26, J. W. F.

New York: Macedon, June 14, J. D. Hood; Rochester, July 9, J. D. Hood; Sea Cliff, Long Island, July 9, A. D. MacGillivray.

Ohio: Salineville, February 6, A. D. MacGillvray.

Bourletiella hortensis (Fitch)

Plate VIII, fig. 59-65

This common species, known as the garden springtail, was redescribed and discussed in Folsom, 1924.

Packard's types of *quadrisignatus* and Harvey's types of *albamaculata*, which I have studied, are *hortensis* Fitch.

The identity of the European *pruinosus* Tullberg with hortensis Fitch

was learned through exchanges of specimens that I made with Dr. C.
Schäffer and with Mr. William Evans.

The following references complete the synonymy of *hortensis,* includ-
ing also that of the questionable species *signata* (Nicolet) Agren.

Smynthurus hortensis Fitch, 1863.
Sminthurus signatus Ågren, 1903.
Bourletiella signata Shoebotham, 1914; Denis, 1921; Stach, 1921, 1929.
Bourletiella pruinosa Denis, 1922; Handschin, 1924.
Sminthurus hortensis Folsom, 1924.
Bourletiella hortensis Carpenter, 1925; Davies, 1925, 1926; Folsom, 1928; Denis,
1930; Mills, 1930a, 1930b; Womersley, 1932.

Denis (1930) correctly notes that the two lateral teeth of the unguis
are at different levels (Fig. 59), and that the seta of the unguiculus is sub-
apical in position (Fig. 60). He found only three setae on the lobe of the
tenaculum. Three setae are common in North American specimens also
(Fig. 61), and rarely only two are present.

In the North American specimens that I have examined, the subanal
appendages of the female are consistently like figure 62. I add figures of
the eyes (Fig. 63, 64), which differ from those of *arvalis,* and give a new
figure of the mucro (Fig. 65).

B. hortensis is a common species every year in fields and gardens in
May and June. It is usually common on flowers of dandelion, the pollen of
which it eats. In occasional years this species appears in enormous numbers
and becomes a pest of great, though local, importance on seedlings. It has
often ruined entire fields of young onions, cucumbers, cabbages, beets,
turnips, mangolds, etc. This garden springtail has been destructive to more
than thirty kinds of cultivated plants, and its list of food plants includes
all the common plants of the truck garden and tobacco and wheat as well.

My numerous records of this species are from Maine, Massachusetts,
Connecticut, New York, New Jersey, Pennsylvania, Virginia, Ohio, Illinois,
Tennessee, Iowa, Ontario, and Nova Scotia.

Bourletiella spinata (MacGillivray)

Plate VIII, fig. 66, 67; Plate IX, fig. 68-76

Smynthurus spinatus MacGillivray, 1893, 1894; Mills, 1930b.
Sminthurus spinatus Guthrie, 1903.
Bourletiella spinata Folsom, 1928.

Female: Olivaceous. Head olivaceous between the eyes and around
the mouth; face purplish; genae pale. Body olivaceous to purplish or
fuscous above. On the dorsum, anteriorly, is a large transverse elliptical
pale area bounded behind by a curving row of minute pale spots; an an-
terior median dorsal white stripe is usually present; on the middle of the
dorsum are several groups of circular white spots; posteriorly, on each side,
a longitudinal row of four to ten round equal white spots. Body laterally
olivaceous with abundant rounded or elongate white spots intermixed with
black areas. At the base of the furcula there is a large pale area on each
side of abd. 4. Sternum olive posteriorly. Ant. 1. 2. and 3 pale purple
with dark purple apical ring; ant. 4 purple. Legs purplish or fuscous,
mottled with olive or whitish blotches; apex of tibiotarsus blackish purple.

Manubrium and dentes mottled with purple; mucro pigmented. Eyes (Fig. 66) 8+8, two smaller than the others. Median ocellus present. Antennae almost twice as long as the head, with segments about as $1 : 3 : 4.5 : 9$; ant. 4 with at least 17 subsegments, there being 15 evident subsegments between the basal and the apical segments. Ant. 3 organ as in figure 67. Unguis (Fig. 68, 69) with one inner tooth. Unguiculus rudimentary, spini-form, on the fore and mid feet (Fig. 68); well developed, elliptical, apically setaceous, on the hind feet (Fig. 69). Tenent hairs three. Dentes (Fig. 70) each with a row of long closely set setae on each side; each of the mesal setae (excepting about eight proximal ones) has a posterior striated mem-branous expansion, as in figure 71; the lateral setae are simple. Mucrones (Fig. 70, 72) obovate in dorsal aspect, lamellate, the outer lamella coarsely and irregularly toothed, or almost entire. Mucronal seta absent. Rami of tenaculum (Fig. 73, 74) tridentate, with a basal appendage; anterior lobe elongate, with two terminal setae. Subanal appendages of female (Fig. 75) six-sevenths as long as mucro. Clothing of abundant curving simple white setae of moderate length; many of these, especially those between the eyes, arise each from a round pale spot. Integument smooth. Maximum length, 2.3 mm.

Male: Smaller than the female and more blackish. Head and body dorsally olivaceous to fuscous. Head blackish laterally. Body blackish laterally with small white or yellow spots. Ant. 1 and 2 pale yellow, black apically; 3 pale yellow or pale purple, black apically; 4 blackish purple. Antennae more than twice as long as the head, with segments about as $1 : 3.5 : 4.5 : 9$. Legs pale yellow, tibiotarsi black apically. Dentes pale yellow; manubrium with a little apical pigment. Anal segment with a pair of stout porrect spines (Fig. 76). Structurally, the antennae, claws, and furcula are as in the female.

This species is very variable in coloration. The prevailing color is sometimes clear green. Some individuals have a broad olivaceous median dorsal stripe.

Two cotypes, given to me by Dr. MacGillivray, have enabled me to identify this species definitely.

B. spinata is common on standing water and on wet vegetation and debris on the shores of ponds and streams. Its ability to leap on the surface of water is exceptional, owing to the special structural adaptations of the furcula.

Maine: Brownsville, June 25, H. Wilder.

Massachusetts: Cambridge, April 29, J. W. F.; Arlington, May 23, June 19, 27, July 10, 16, November 16, J. W. F.; Belmont, October 23, J. W. F.; Waltham, May 9, J. W. F.; Stony Brook, May 16, August 4, J. W. F.; Norwood, August 26, J. W. F.; Dedham, July 12, J. W. F.; East Ware-ham, H. J. Franklin; Mt. Tom, September 10, G. Dimmock.

New York: Ithaca, A. D. MacGillivray.

Illinois: Volo, June 16, T. H. Frison.

Iowa: Gilbert, June 13, H. B. Mills.

Kentucky: March 31, F. M. Webster.

Louisiana: June 6, J. W. F.

Texas: Bryan, March 28, W. L. Owen, Jr.

Minnesota: J. E. Guthrie.

Manitoba: Birtle, July 1-7, R. D. Bird.

Sminthurus purpurescens (MacGillivray)

Plate X, fig. 77-80

Papirius purpurescens MacGillivray, 1894.

Blackish purple. Head between the antennae washed with yellowish. Ant. 2 white. Legs, manubrium, and dentes dark. Eyes 8+8, with one small inner eye on each side. Ant. 1 one-third as long as ant. 2. "Claws short, stout, outer broadly rounded, with two teeth, one at middle, the other at base, inner claw nearly as long as outer, more slender, with two bristles at tip." (MacGillivray.) Tenent hairs present. Dentes subequal to manubrium in length, with simple dorsal setae. Mucro (Fig. 77) one-third as long as dens, apically rounded in lateral aspect, with low rounded teeth; outer margin entire except for two distal teeth and traces of four proximal teeth; inner margin with ten teeth; mucronal seta present. Rami of tenaculum (Fig. 78) tridentate; anterior lobe with four stout setae. Subanal appendages of female (Fig. 79, 80) about four-fifths as long as mucro, elongate, with several terminal branches. Clothing of numerous stiff or curving setae of moderate length. Anal segment with long stiff setae, some of which are feebly subclavate, while some are slightly roughened, though none are fringed. Bothriotricha three on each side of the body; two on each side of the genital segment. Length, 2 mm.

Apparently there is only one type of this species, and in that specimen the antennae and claws are broken off. MacGillivray described the species as a *Papirius,* although he said that the last two antennal segments were lacking. The species does not belong in Dicyrtominae but falls in Sminthurinae, and is apparently a *Sminthurus*.

New York: Sea Cliff, Long Island, N. Banks.

Sminthurus floridanus (MacGillivray)

Plate I, fig. 3; Plate X, fig. 81-85

Smynthurus floridanus MacGillivray, 1893.
Smynthurus floridana MacGillivray, 1894.

Abd. 4 with a large posterior median dorsal protuberance (Fig. 3, 81). Between this and the head is a large subtriangular blackish purple area. Anogenital segment marked with blackish dorsally, otherwise olive mottled with brown. Abdomen laterally olive mottled with light brown or purple. Sternum olive. Head blackish purple, with paler lines; oral region olive. Ant. 1 dark purple; 2, 3, and 4 olive. Legs pale olive, Furcula un.-pigmented. Ant. 2 : 3 : 4 about as 2 : 3 : 10. Ant. 4 (Fig. 82) with 20 subsegments (18 intermediate segments). Unguis (Fig. 83) stout, with a tunica, an inner tooth at the middle, and an outer tooth near the base. Unguiculus with a subapical filament. Mucro (Fig. 84) with outer margin entire, inner margin with several blunt teeth, apex obliquely truncate, without mucronal seta. Rami of tenaculum (Fig. 85) tridentate, anterior lobe with two apical setae. Body with long white setae, curving on the anterior dorsum, stiff posteriorly. Length, 1.6 mm.

This incomplete description is based upon the original description and the unique and defective type. It should, however, enable this peculiar species to be recognized.

Florida: N. Banks.

Sminthurus packardi (Folsom)

Plate X, fig. 86-88; Plate XI, fig. 89-99

Paprius Texensis Packard, 1873 (in part).
Smynthurus packardii Folsom, 1896b.

Body subtriangular, dilated broadly behind (in many of the individuals), pale luteous or whitish, spotted with black dots dorsally, with a large anterior pale area. The dorsal pattern of the anal segment is essentially as in figure 86. Head white between the eyes, with a wide pale median stripe down the face. Antennae purplish, or 1 and 2 pale yellow. The precoxae, coxae, and trochanter are each banded with purple, and a band occurs also at the middle of the femur and at the base of the tibiotarsus, which is also purple apically. Manubrium pigmented apically or almost entirely, and dens basally and dorsally, with purple. Eyes on conspicuous black patches, 8+8 (Fig. 87). Antennae about twice as long as the head, with segments about as 1 : 2 : 3 : 8; ant. 4 with 16 or 17 intermediate segments between the basal and apical segments. Ant. 3 with several proximal macrochaetae (the longest setae of the segment) and with sensory organ as in Figure 88. Unguis (Fig. 89, 90) with a tunica, an inner tooth at the middle, a pair of long serrate pseudonychia, and a long outer proximal tooth. Unguiculus (Fig. 89) with an inner tooth and a subapical seta extending as far as, or beyond, the opposite unguis. Tenent hairs absent, represented by two long simple setae. In both sexes a hemispherical anterior lobe is present on the fore legs between the distal precoxa and the coxa (Fig. 91, 92); an elongate anterior lobe on the mid legs, on the distal precoxa (Fig. 93, 94); and a small anterior lobe on the hind legs, on the proximal precoxa (Fig. 95). Mucro (Fig. 96, 97) one-third to two-fifths as long as dens, obliquely truncate apically, with a lateral seta; outer dorsal margin entire, inner margin with usually 9 or 10 large teeth (8, 11 and 14 were also seen). Rami of tenaculum tridentate (Fig. 98); anterior lobe with four setae. Anal appendages of female (Fig. 99) simple, arcuate, three-fourths as long as mucro. Clothing of long curving white hairs, minutely roughened. Bothriotricha of abd. 4, 3+ 3; of abd 5, 2+2, each pair arising from the same lateral tubercle. Integument minutely tuberculate. Maximum length, 1.75 mm.

The coloration is very variable.

This species is common in Texas under dead leaves. In one locality (Avery) it was damaging tomatoes, according to Mr. H. B. Mills.

Texas: Waco, G. W. Belfrage; Avery, April 5, H. B. Mills; Bryan, March 25, April 12, H. B. Mills; College Station, March 3, September 4, November 5, H. B. Mills.

Sminthurus fitchi (Folsom)

Plate XII, fig. 100-105

Smynthurus fitchii Folsom, 1896d.

Pale translucent yellowish green, in individuals of moderate size. The contents of the alimentary canal, showing through the skin, appear as a large, blackish, backward-pointing triangle, extending the length of the dorsum. Body in largest individuals dusky throughout, with large pale rounded spots laterally. Head pale green. Ant. 1 and 2 white; 3, white to dilute purple; 4, dark purple. Legs and furcula pale green. Eyes (Fig.

100) 8+8, the inner eye smaller. Antennae four-fifths longer than the head, with segments about as 2 : 3 : 5 : 14; ant. 4 with 17 subsegments (15 intermediate segments); ant. 3 with macrochaetae proximally. Unguis (Fig. 101, 102) with a tunica, one inner tooth at the middle, and a pair of long serrate pseudonychia. Unguiculus with an inner tooth, absent on the fore feet, and a subapical filament about two-thirds as long as the unguiculus. Tenent hairs absent. Mucro (Fig. 103) one-third as long as dens, with apex obliquely truncate; outer margin entire, inner margin with 8 to 10 coarse, blunt, irregular teeth; mucronal seta present. Rami of tenaculum (Fig. 104) tridentate, without basal appendage; anterior lobe with three setae. Subanal appendages of female (Fig. 105) simple, spine-like, curving, three-fourths as long as mucrones. Dorsum with long curving simple white setae; face with dense short curving white setae. The largest setae are minutely roughened on all sides. Integument minutely pseudo-tuberculate. Maximum length, 2.2 mm.

S. *fitchi* is close to S. *viridis* L. The principal difference between the two species is in the mucrones, both margins of which are untoothed in *viridis*.

This species was common in Massachusetts on wet logs and sticks in pine woods. Dr. H. J. Franklin swept it from vines in a cranberry bog.

Massachusetts: Arlington, July 22, 30, August 19, 21, September 25, J. W. F.; Belmont, May 25, J. W. F.; East Wareham, September 1, H. J. Franklin.

Dicyrtomina opalina (Folsom)

Plate XII, fig. 106-110

Papirius opalinus Folsom, 1896c.

General color orange-rufous or ferruginous. Anterior dorsum translucent orange-ochraceous, often with a long broad median shading of green, due to chlorophyll in the mid intestine; posterior dorsum and sides orange-rufous to dark ferruginous, often with a tinge of maroon, the general color being the combined effect of minute orange-ochraceous and ferruginous mottlings. Sternum pale yellow, with three pairs of buff-yellow tubercles. Head, first two antennal segments, and legs pale orange-ochraceous; ant. 3 and 4 purple. Dentes pale orange-rufous. Eyes (Fig. 106). 8+8, the inner eye smaller. Antennae four-fifths longer than the head, with segments about as 2 : 10 : 12 : 3; without subsegments. Claws stout (Fig. 107). Unguis with a tunica, a pair of serrate pseudonychia, a pair of lateral teeth on each side, and two inner teeth: one-fourth and one-half the distance from the apex, respectively. Unguiculus with an inner proximal tooth and a subapical seta. Dens with two dorsal rows of simple setae. Mucro (Fig. 108) one-third as long as dens, with both dorsal margins serrate; outer teeth about 26; inner, about 21. Rami of tenaculum (Fig. 109) tridentate; anterior lobe with two setae. Subanal appendages of female (Fig. 110) simple, spinelike, feebly curving, one-half as long as mucrones. Anterior dorsum naked; posterior dorsum with a few short white setae upon minute round orange-ochraceous spots. Head with a few short setae on the front; vertex almost naked. Integument finely tuberculate. Maximum length, 1.6 mm.

This species occurred with *P. vittata* in a greenhouse, where it fed on algae on flower pots.

Massachusetts: Cambridge, February 2, 3, 16, J. W. F.

Dicyrtoma hageni (Folsom)

Plate I, fig. 4; Plate XIII, fig. 111-117

Papirius hagenii Folsom, 1896a.

Abdomen blackish purple above with a posterior dorsal pattern of yellowish brown, variable in form, sometimes almost absent, typically as in figure 4. The pattern may, however, consist of five spots: a median elongate mark widening behind; an anterior pair of spots more or less three-lobed; and a posterior pair of transverse marks. The blackish pigment covers the sides and meets the pale yellow sternum with a well defined but zigzag margin. Th. 1 and often th. 2 yellow. Abd. 6 yellow. Head orange-ochraceous, oral region orange, eye spots black. First two antennal segments orange, last two purplish. Legs yellow, paler basally. Furcula pale yellow basally, becoming white distally. Eyes (Fig. 111) 8+8, two smaller than the others. Antennae three-fifths longer than the head, with segments about as 1 : 4 : 5 : 1.5. Ant. 3 and 4 not subsegmented. Ant. 3. organ of two simple papillae. Unguis (Fig. 112) without a tunica, with a pair of distal outer teeth, with a pair of weakly serrate pseudonychia, with a constant inner tooth one-third the distance from the apex, and often with traces of a proximal and a distal inner tooth. Unguiculus (Fig. 113) with an inner basal tooth and a strong knobbed subapical filament. Tenent hairs absent. Dentes with two dorsal rows of setate, mostly serrate (Fig. 114); outer row of 8 setae of which the proximal one or two are simple; in addition a lateral subapical serrate seta is present. Mucro (Fig. 115) with both dorsal margins minutely serrate; outer teeth about 33, inner teeth about 40. Rami of tenaculum (Fig. 116) tridentate, with a basal papilla; anterior lobe with 3 or 4 setae. Subanal appendages of female (Fig. 117) spinelike, two-thirds as long as mucro. Abdomen posteriorly with short erect simple setae. Integument minutely tuberculate. Maximum length, 1.5 mm.

The distal swellings on ant. 3 suggest segmentation, but no subsegments are actually differentiated.

The only examples of this species that I have seen are those collected by myself, in humus, mostly among dead pine needles.

Massachusetts: Arlington, June 6, 12, 29, July 17, August 15, September 21, 25, 30, J. W. F.; Stony Brook, June 12, J. W. F.

Ptenothrix unicolor (Harvey)

Plate XIII, fig. 118-122; Plate XIV, fig. 123-128

Papirius unicolor Harvey, 1893.
Papirius pini Folsom, 1896a.
Ptenothrix unicolor Folsom, 1928.

Light brownish purple. Dorsum dark. Laterally with many pale spots of various forms. Sternum pale. Head, anogenital segment and bases of legs paler, more brownish. Ant. 1 and base of ant. 2 paler, brownish; remainder of antennae dark purple. Tibiotarsi dark purplish. Manubrium and dentes tinged with purple. Eyes (Fig. 118) 8+8, two smaller than the others. Median ocellus present. Antennae four-fifths as long as the body. Ant. 3 with six equal intermediate segments between the long basal segment and the short swollen apical portion. Ant. 4 with four or five

evident proximal segments before the conical end-segment. Ant. 3 sense organ (Fig. 119) with a pair of papillae, without guard setae. Unguis (Fig. 120, 121) with two inner teeth, and a pair of lateral teeth on each side. Unguiculus (Fig. 120) with a strong inner tooth and a subapical seta exceeding the unguis. Dens with two dorsal rows of setae, mostly serrate (Fig. 122); outer row of 8 setae (occasionally 9), the proximal seta simple, with an additional subapical lateral enlarged seta (Fig. 123); inner row of 10 setae, the two proximal of which are simple. Dens with 4 long outstanding dorsal hairs and with 7 strong distal ventral setae: 4 median, 2 outer and 1 inner. Mucro (Fig. 123) almost one-third as long as dens, with both dorsal margins serrate; outer teeth 19-22, inner teeth 23-30. Rami of tenaculum (Fig. 124) tridentate; anterior lobe slender, with 4 apical setae (sometimes 3).

Subanal appendages of female (Fig. 125) simple, spinelike, from one-half to two-thirds as long as mucro. Genital regions as in Figures 126 and 127. Dorsum anteriorly with strong spinelike setae (Fig. 128); posteriorly with abundant minute erect setae. Bothriotricha: one dorsal pair from the large tubercles on abd. 4; one lateral abdominal pair; one dorsal pair on the anal segment; one antero-lateral pair on the subanal lobes. Length, 1.6 mm.; maximum, 2.5 mm.

Individuals often occur that are much browner than usual.

Among the many specimens that I studied were some of Harvey's cotypes.

P. unicolor is one of our commonest sminthurids. It occurs under damp logs, under damp loose bark, in humus and in moss, and is common on agarics and other fungi in company with *P. marmorata*.

Maine: Orono, October, November 8, F. L. Harvey.

New Hampshire: Pinkham, July 23, C. A. Frost.

Massachusetts: Arlington, May 27, September 5, 12, 19, 25, October 14, J. W. F.; Stony Brook, June 12, J. W. F.; Dedham, July 12, 21, J. W. F.; Norwood, August 26, J. W. F.; Sherborn, June 17, 28, September 17, October 30, C. A. Frost; Wayland, September 18, November 2, C. A. Frost; Natick, August 17, 24, September 14, 21, C. A. Frost; Framingham, March 30, June 13, 17, July 17, C. A. Frost.

New York: Ithaca, July 25, A. D. MacGillivray; Lakeville, October 8, E. A. Maynard.

Illinois: Homer, April 24, May 5, 11, 12, 22, 28, October 13, J. W. F.; Urbana, October 4, J. W. F.

Wisconsin: Two Rivers, August 27, J. W. F.

Canada: Arnprior, Ontario, June, July, August, C. Macnamara.

Ptenothrix olympia (MacGillivray)

Plate II, fig. 5, 6; Plate XIV, fig. 129-134

Papirius olympius MacGillivray, 1894.

Figures 5 and 6. ''Reddish, spotted with dark brown, in young specimens purplish.'' ''Abdomen and thorax with two sinuate brown bands on each side of the dorsum, the middle ones meeting at the apex and base of the thorax, and on the basal half of the abdomen, also a band extending from this basal transverse band of the abdomen along the middle of the back towards the head, bilobed in front, a triangular spot just before the

apex of the abdomen and promiscuous mottlings on the side, brown.''
(MacGillivray,) Sternum pale. Head mostly pale. Vertex with a median
dorsal band. Ant. 1 pale; 2 pale purple, dark apically; 3 and 4 dark purple.
Ant. 2 has numerous round black spots of various sizes. Coxa, trochanter,
and femur pale; tibiotarsus pale proximally, purple distally. Furcula
pale yellow; often purplish laterally at the apex of the manubrium and
the base of the dens. Eyes 8+8. Antennal segments about as 1 : 5 : 4 : 1;
ant. 3 (Fig. 129) with 6 equal subsegments between the basal and the
apical subsegments; ant. 4 with 4 subsegments. Unguis (Fig. 130, 131)
slender, with two inner teeth, two lateral teeth on each side, and two small
outer teeth. Unguiculus slender, with a inner spine and a long subapical
filament. Dentes with two dorsal rows of setae, mostly serrate; outer row
of 9 setae, the 2 proximal simple, the remaining 7 successively shorter and
broader, and coarsely serrate (Fig. 132). An additional serrate seta occurs
laterally and subapically. Mucro almost one-third as long as dens, each
margin with about 25 teeth (Fig. 133). Rami of tenaculum (Fig. 134)
tridentate; anterior lobe with five setae. Head and body with stiff white
setae; dorsum anteriorly with strong spikelike setae; posteriorly with
abundant minute stiff setae; anal segment with long stiff setae dorsally
and weaker setae posteriorly. Maximum length, 3 mm.

Redescribed from several of the cotypes.

Washington: Olympia, T. Kincaid.

Ptenothrix texensis (Packard)

Plate XIV, fig. 135; Plate XV, fig. 136, 137

Papirius texensis Packard, 1873 (in part); Folsom, 1896b.

Pale luteous marbled with brown and black; head paler. Antennae
pale reddish brown, or purple, darker distally. Legs white, banded with
purple: trochanter banded; femur with a distal band; tibiotarsus with a
proximal and a middle band. Eyes probably 8+8, the inner eye one-half
the diameter of the others. Antennae 1.8 times as long as the head, with
segments about as 1 : 5 : 5.5 : 2, or 1 : 6 : 7 : 2; ant. 3 with ten distal
subsegments; ant. 4 unsegmented. Unguis (Fig. 135) with two inner teeth,
either or both of which may be obscure, and two obscure lateral teeth on
each side (these teeth being smaller than in figure 135). Unguiculus with
a strong inner spine and with a long subapical filament exceeding the un-
guis. Tenent hairs absent. Dens three to four times as long as mucro,
with two dorsal series of setae: an outer row of 8 and an inner row of 9;
outer row with 3 to 5 proximal simple setae and 5 to 3 distal serrate setae;
inner row with 4 proximal simple setae and 5 distal serrate setae; the
serrate setae are relatively slender and few-toothed (Fig. 136). Mucro
(Fig. 137) with three rounded apical lobes and with both dorsal margins
serrate; the teeth small and rounded. Clothing of long stout stiff setae
on the vertex, anterior dorsum of the body, and sides of dentes. There
are a few short setae above the mouth and on the posterior dorsum. Abd.
6 with long curving setae. Length, 1.3 mm.

This description and figures were made from Packard's types.

Texas: Waco, G. W. Belfrage; College Station, October 9, H. B. Mills.

Ptenothrix marmorata (Packard)

Plate II, fig. 7, 8; Plate XV, fig. 138-143

Papirius marmoratus Packard, 1873; MacGillivray, 1891.
Papirius testudineatus Folsom, 1896a.
Ptenothrix testudineatus Handschin, 1928a.
Ptenothrix marmoratus Folsom, 1928.

Dark purple, with conspicuous wax-yellow patterns. These patterns are variable but essentially as in figures 7 and 8. The median dorsal stripe on the anterior half of the abdomen is constant. The pair of large dorsal tubercles on abd. 4 are white. Sternum pale yellow. Ventral tube purple. Ant. 1 white, purple apically; 2 pale purple; 3 and 4 purple. Trochanter and tibiotarsus purple; femur purple, white basally and apically. Furcula pale purple, unpigmented in the young. Eyes (Fig. 138) 8+8, two smaller than the others. Antennal segments about as 1 : 8 : 10 : 2; ant. 3 with 8 subsegments (6 intermediate); ant. 4 with 5 subsegments (4 basal subsegments being evident). Unguis (Fig. 139) with two inner teeth, and a pair of lateral teeth on each side. Unguiculus with a strong inner spine and a subapical seta extending as far as the unguis or a little beyond it. Dens with two dorsal rows of setae; (1) an outer row of 8 setae, of which the proximal 1 or 2 are simple, while the others successively become broader basally and more serrate (Fig. 140, 141); with an additional seta, usually serrate, subapical and lateral in position; (2) an inner row of 10 setae, the proximal 2 simple and the others serrate. Dens with four very long outstanding dorsal setae. Mucro one-third as long as dens, with both dorsal margins serrate (Fig. 142); outer teeth about 20, inner teeth about 27. Subanal appendages of female (Fig. 143) simple, spinelike, slightly curving, about one-half as long as mucro. Dorsum of body with a few long setae anteriorly and many shorter ones posteriorly; head with short stiff setae. Length, 2.2 mm.

This species is common under damp logs and under loose damp bark. It often occurs on fungi, especially agarics.

Maine: Brunswick, September 10, A. S. Packard; Orono, F. L. Harvey.

New Hampshire: Mt. Madison, July 24, C. A. Frost; Pinkham, July 23, C. A. Frost; Walpole, July 14, J. W. F.

Massachusetts: Arlington, September 5, 19, 21, 25, J. W. F.; Belmont, May 5, J. W. F.; Cambridge, October 22, J. W. F.; Framingham, March 30, C. A. Frost; Natick, August 17, C. A. Frost; Sherborn, June 17, C. A. Frost; Stony Brook, July 16, J. W. F.; Wayland, December, C. A. Frost; Woods Hole, September 15, A. S. Packard.

New York: Ithaca, July 1, A. D. MacGillivray; Schuyler County, June 5, C. R. Crosby, July 12, A. Wolf.

Maryland: College Park, January 20 (in a greenhouse), E. N. Cory.

Illinois: Homer, October 11, J. W. F.

Texas: College Station, October 14, H. B. Mills.

Canada: Arnprior, Ontario, C. Macnamara; Birtle, Manitoba, July, R. D. Bird.

Ptenothrix vittata (Folsom)

Plate XVI, fig. 144-151

Papirius vittatus Folsom, 1896c.

Dorsal color pattern as in figure 144. Younger individuals dark purple

above with pearly markings, lavender or lilac beneath; older ones maroon to almost black above, the sides mottled with several shades of purple and brown. Head purple, with a broad white band across the front (Fig. 145); oral region whitish. Ant. 1 brownish; 2 brownish basally, purple at middle, pearly apically; 3 and 4 purple. Legs purple and wax yellow; trochanter purple; femur purple apically; tibiotarsus distally purple, proximally pale yellow or whitish with two wide purple bands. Manubrium purple; dentes pale lilac. Eyes (Fig. 146) 8+8, two smaller than the others. Antennae about twice as long as the head, with segments about as 1 : 6-7 : 7-9 : 2; ant. 3 distally subsegmented, with 5 equal segments between the basal and the apical segments; ant. 4 with apparently 5 subsegments. Unguis (Fig. 147) with two inner teeth, and two lateral teeth on each side. Unguiculus with an inner basal spine and a long subapical filament exceeding the unguis, longest on the fore feet. Dens with two dorsal rows of setae, mostly serrate (Fig. 148); outer row of 7 or 8, the proximal 3 simple. Mucro (Fig. 149) with both dorsal margins serrate; outer teeth about 26-29; inner teeth about 43. Anterior lobe of tenaculum with two pairs of curving apical setae. Subanal appendages of female (Fig. 150, 151) spinelike, straight or weakly curving, one-third as long as mucrones. Integument finely tuberculate. Maximum length, 3.3 mm.

Thus far this species has been found only in greenhouses. It has been taken on wet decaying wood and on alga-coated flower pots.

Massachusetts: Cambridge, February 2, 16, 18, 23, 25, March 15, J. W. F.

Maryland: College Park, March 14, P. Garman; Silver Spring, November 18, G. D. Reynolds.

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PLATE I

Fig. 1. *Sminthurinus quadrimaculatus* (Ryder).

Fig. 2. *Sminthurinus elegans* (Fitch).

Fig. 3. *Sminthurus floridanus* (MacGillivray).

Fig. 4. *Dicyrtoma hageni* (Folsom).
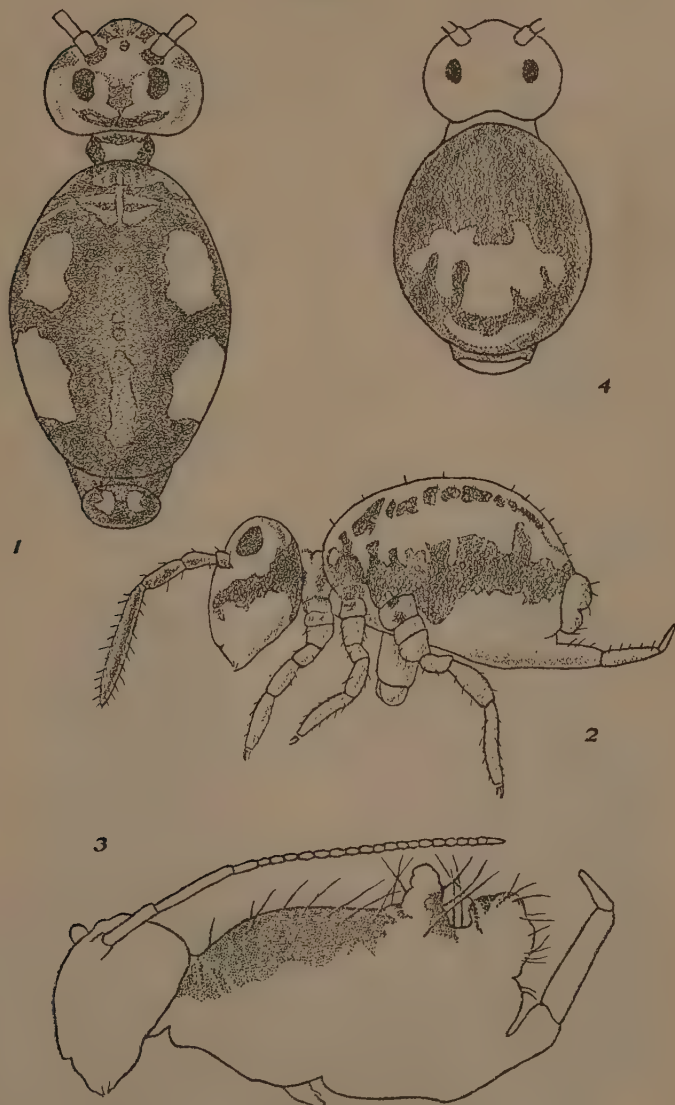
PLATE I

PLATE II

PLATE II

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PLATE III

Sminthurinus remotus (Folsom)

Fig. 9. Eyes of left side.

Fig. 10. Proximal tubercle of left ant. 3.

Fig. 11. Right fore foot.

Fig. 11. Right fore foot.

Fig. 12. Left Mucro.

Sminthurinus minutus (MacGillivray)

Fig. 13. Eyes of right side.

Fig. 14. Left ant. 3 sense organ.

Fig. 15. Proximal tubercle of left ant. 3.

Fig. 16. Left mid foot.

Fig. 17. Right mucro.

Fig. 18. Left aspect of tenaculum.

PLATE III

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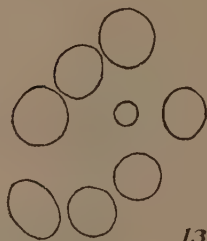
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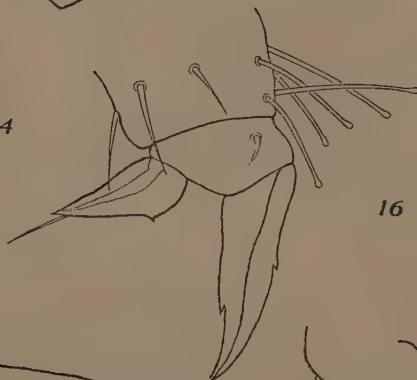
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PLATE IV

Sminthurinus minutus (MacGillivray)

Fig. 19. Left aspect of left subanal appendage of female.
Fig. 20. Posterior aspect of left subanal appendage of female.

Sminthurinus quadrimaculatus (Ryder)

Fig. 21. Eyes of left side.
Fig. 22. Left ant. 3 sense organ.
Fig. 23. Proximal tubercle of right ant. 3.
Fig. 24. Right hind foot.
Fig. 25. Concave aspect of right fore foot.
Fig. 26. Left dens.
Fig. 27. Ventral aspect of end of left dens.

PLATE IV

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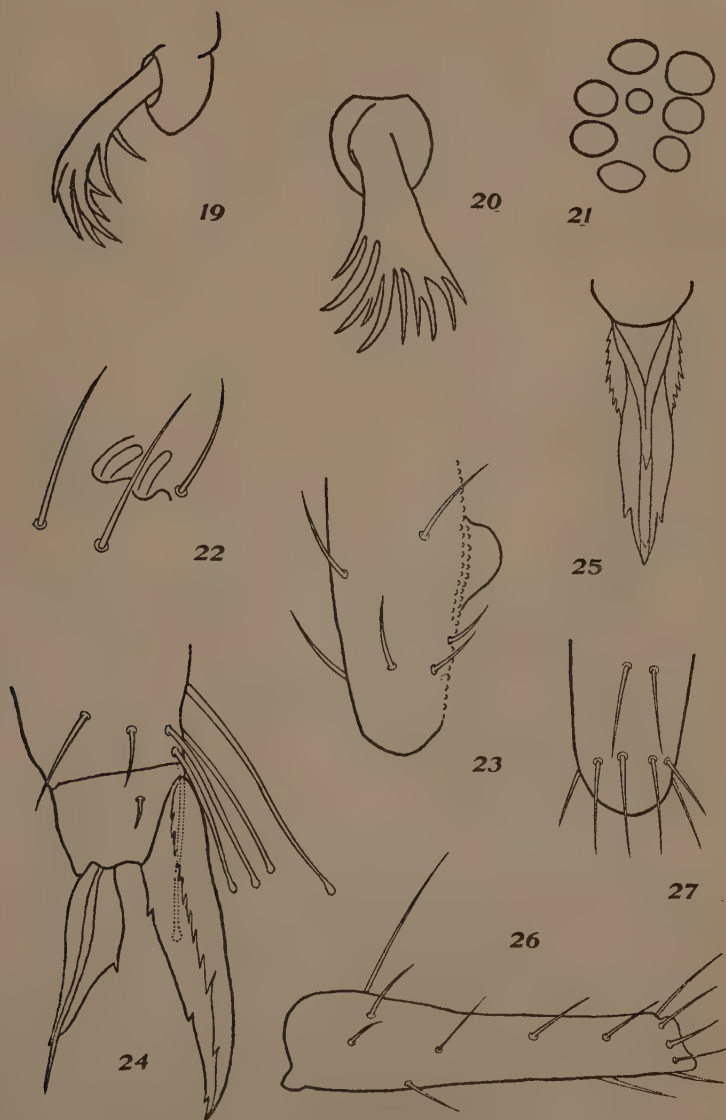
PLATE V

Sminthurinus quadrimaculatus (Ryder)

Fig. 28.   Left mucro.

Fig. 29.   Left aspect of tenaculum.

Fig. 30.   Left aspect of left subanal appendage of female.

Fig. 31.   Posterior aspect of left subnal appendage of female.

Sminthurinus aureus (Lubbock)

Fig. 32.   Eyes of right side.

Fig. 33.   Eyes of left side.

Fig. 34.   Eyes of left side.

Fig. 35.   Proximal tubercle of left ant. 3.

Fig. 36.   Proximal tubercle of left ant. 3.

Fig. 37.   Right fore foot.

Fig. 38.   Left mid foot.

PLATE V
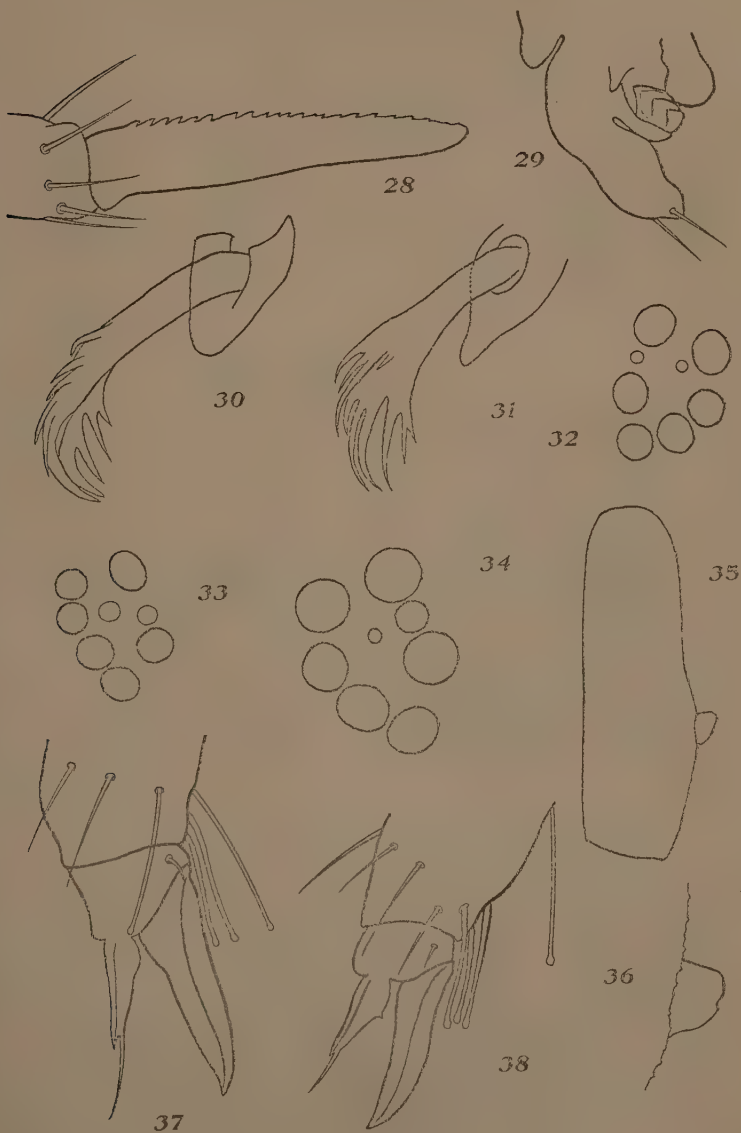
PLATE VI

Sminthurinus aureus (Lubbock)

Fig. 39.   Left hind foot.

Fig. 40.   Right mucro.

Fig. 41.   Right mucro.

Fig. 42.   Left aspect of tenaculum.

Fig. 43.   Left aspect of left subanal appendage of female.

Fig. 44.   Posterior aspect of left subanal appendage of female.

Sminthurinus elegans (Fitch)

Fig. 45.   Eyes of left side.

Fig. 46.   Appendage of proximal precoxa of left mid leg.

Fig. 47.   Left fore foot.

PLATE VI

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PLATE VII

Sminthurinus elegans (Fitch)

Fig. 48. Right hind foot.
Fig. 49. Left mucro.
Fig. 50. Left aspect of tenaculum.
Fig. 51. Left aspect of left subanal appendage of female.

Bourletiella arvalis (Fitch)

Fig. 52. Eyes of right side.
Fig. 53. Fourth antennal segment of left side.
Fig. 54. Right ant. 3 sense organ.
Fig. 55. Fore foot.
Fig. 56. Left mucro.

PLATE VII

PLATE VIII

Bourletiella arvalis (Fitch)

Fig. 57.   Left aspect of tenaculum.

Fig. 58.   Left subanal appendage of female.

Bourletiella hortensis (Fitch)

Fig. 59.   Concave aspect of right hind unguis.

Fig. 60.   Left hind foot.

Fig. 61.   Left aspect of tenaculum.

Fig. 62.   Subanal appendage of female.

Fig. 63.   Eyes of right side.

Fig. 64.   Eyes of right side.

Fig. 65.   Right mucro.

Bourletiella spinata (MacGillivray)

Fig. 66.   Eyes of left side.

Fig. 67.   Left ant. 3 sense organ.

PLATE VIII
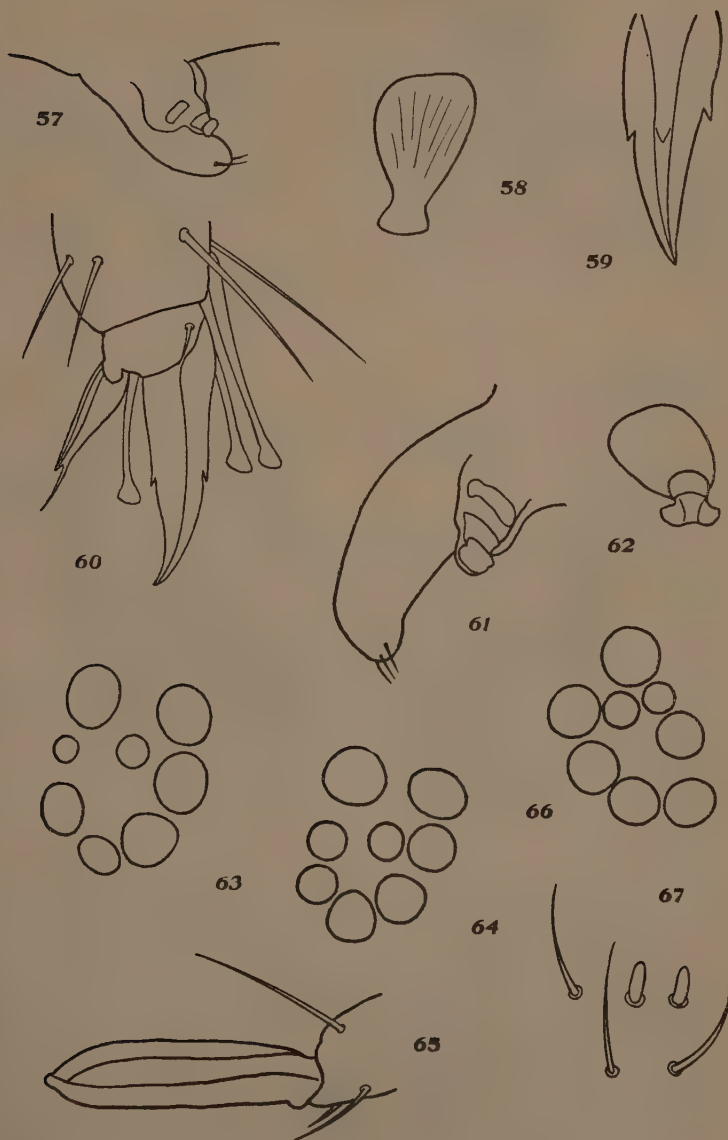
PLATE IX

Bourletiella spinata (MacGillivray)

PLATE IX

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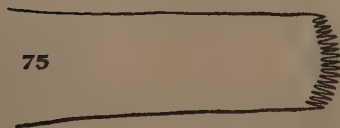
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PLATE X

Sminthurus purpurescens (MacGillivray)

Fig. 77.   Left mucro.

Fig. 78.   Left aspect of tenaculum.

Fig. 79.   Anogenital segment of female.

Fig. 80.   Left subanal appendage of female.

Sminthurus floridanus (MacGillivray)

Fig. 81.   Left aspect of dorsal protuberance of abd. 4.

Fig. 82.   Fourth antennal segment.

Fig. 83.   Left fore foot.

Fig. 84.   Right mucro.

Fig. 85.   Left aspect of tenaculum.

Sminthurus packardi (Folsom)

Fig. 86.   Dorsal pattern of anal segment.

Fig. 87.   Eyes of left side.

Fig. 88.   Left ant. 3 sense organ.

PLATE X
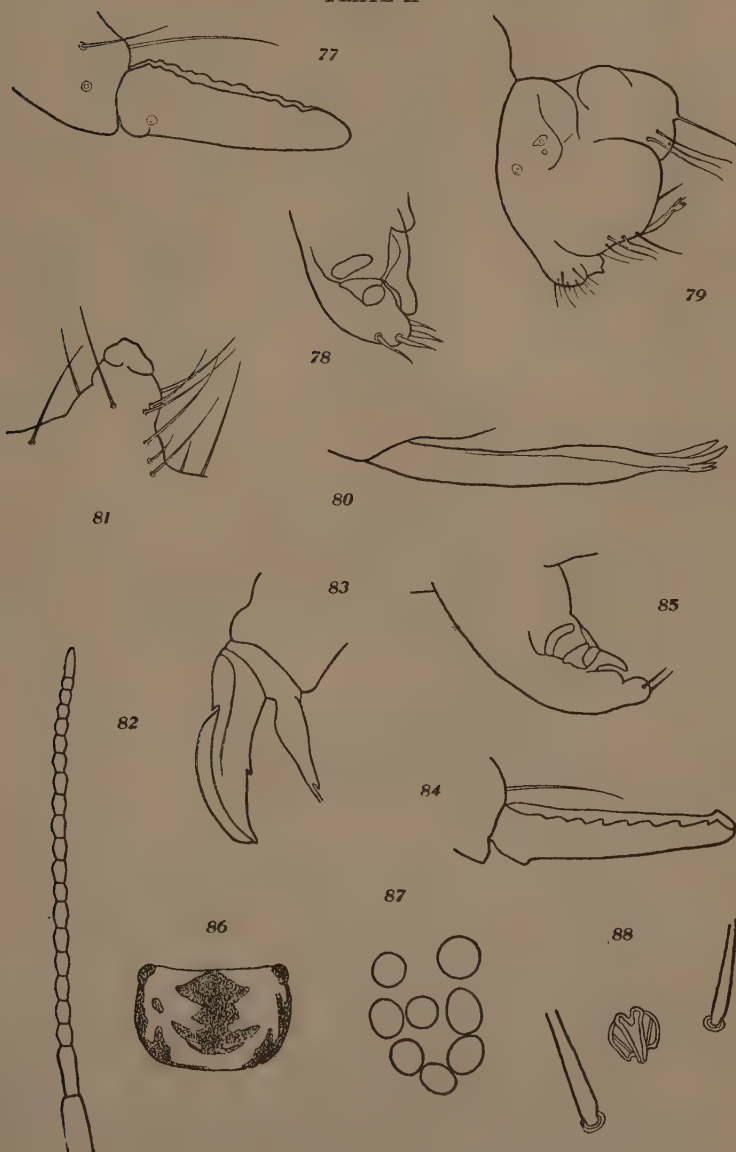
PLATE XI

Sminthurus packardi (Folsom)

Fig. 89. Right mid foot.

Fig. 90. Concave aspect of right hind foot.

Fig. 91. Coxa and distal precoxa of left fore leg.

Fig. 92. Coxa and distal precoxa of left fore leg.

Fig. 93. Coxa and distal precoxa of right mid leg.

Fig. 94. Distal precoxa of left mid leg.

Fig. 95. Proximal precoxa of left hind leg.

Fig. 96. Left mucro.

Fig. 97. Right mucro.

Fig. 98. Left aspect of tenaculum.

Fig. 99. Subanal appendage of female.

PLATE XI
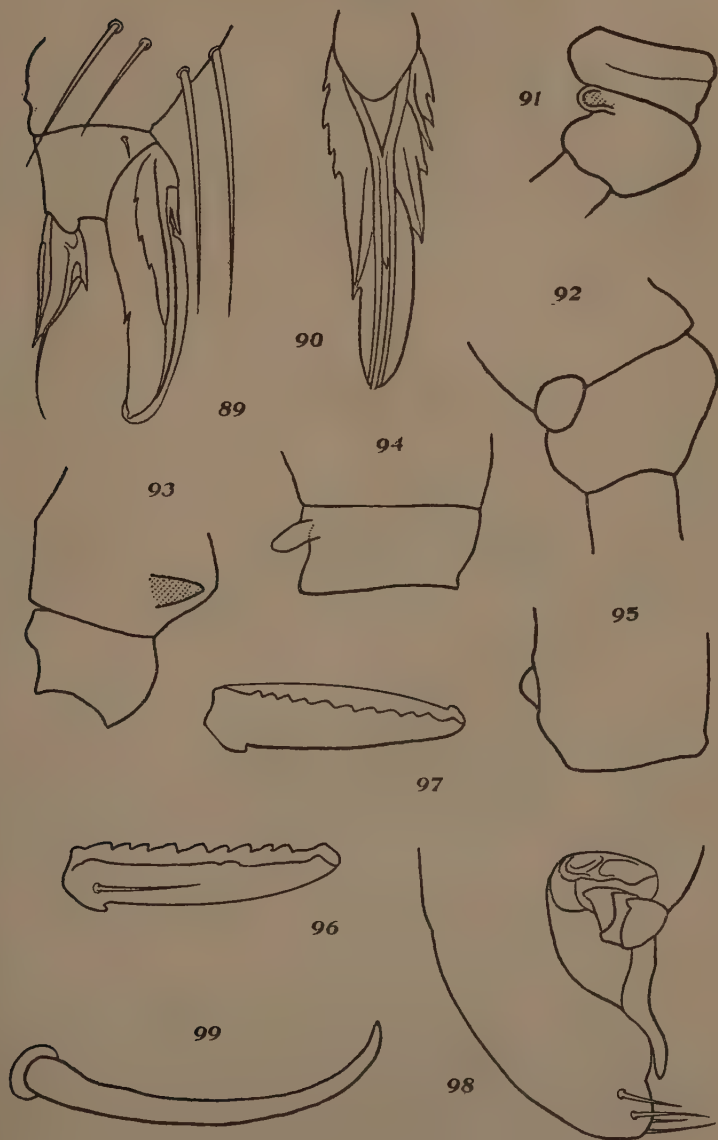
PLATE XII

Sminthurus fitchi (Folsom)

Dicyrtomina opalina (Folsom)

PLATE XII

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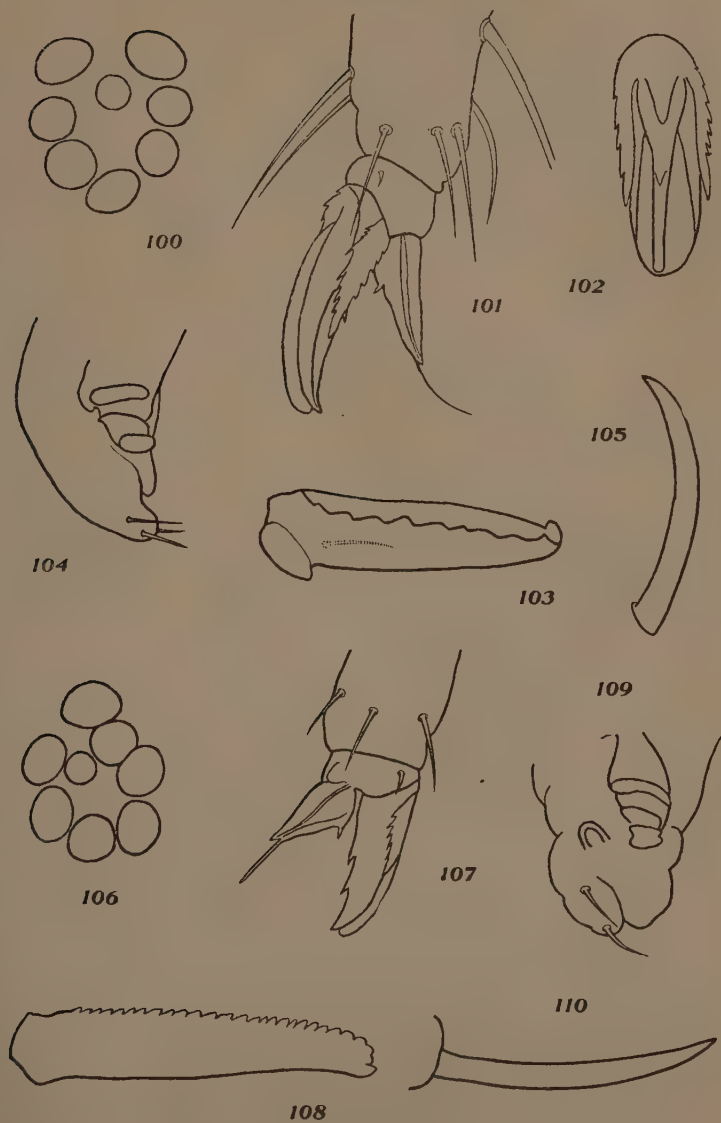
PLATE XIII

Dicyrtoma hageni (Folsom)

Fig. 111.   Eyes of left side.

Fig. 112.   Hind unguis.

Fig. 113.   Left fore foot.

Fig. 114.   Serrate seta from dens.

Fig. 115.   Left mucro.

Fig. 116.   Left aspect of tenaculum.

Fig. 117.   Subanal appendage of female.

Ptenothrix unicolor (Harvey)

Fig. 118.   Eyes of left side.

Fig. 119.   Right ant. 3 sense organ.

Fig. 120.   Right hind foot.

Fig. 121.   Concave aspect of unguis.

Fig. 122.   Serrate seta from dens.

PLATE XIII
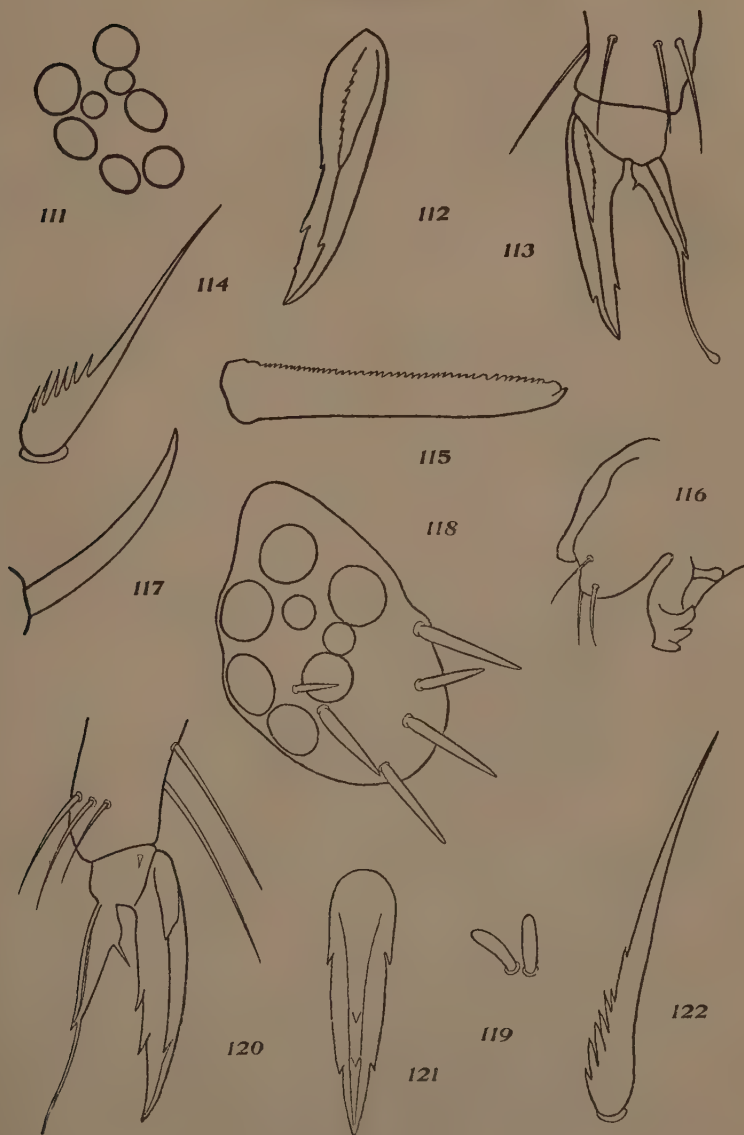
PLATE XIV

Ptenothrix unicolor (Harvey)

Fig. 123. Left mucro and end of dens.

Fig. 124. Left aspect of tenaculum.

Fig. 125. Subanal appendage of female.

Fig. 126. Genital region of male.

Fig. 127. Genital region of female.

Fig. 128. Setae near median dorsal line of abdomen.

Ptenothrix olympia (MacGillivray)

Fig. 129. Last two antennal segments of right side.

Fig. 130. Left mid foot.

Fig. 131. Right hind unguis.

Fig. 132. Serrate seta from dens.

Fig. 133. Left mucro and end of dens.

Fig. 134. Right aspect of tenaculum.

Ptenothrix texensis (Packard)

Fig. 135. Right fore foot.

PLATE XIV
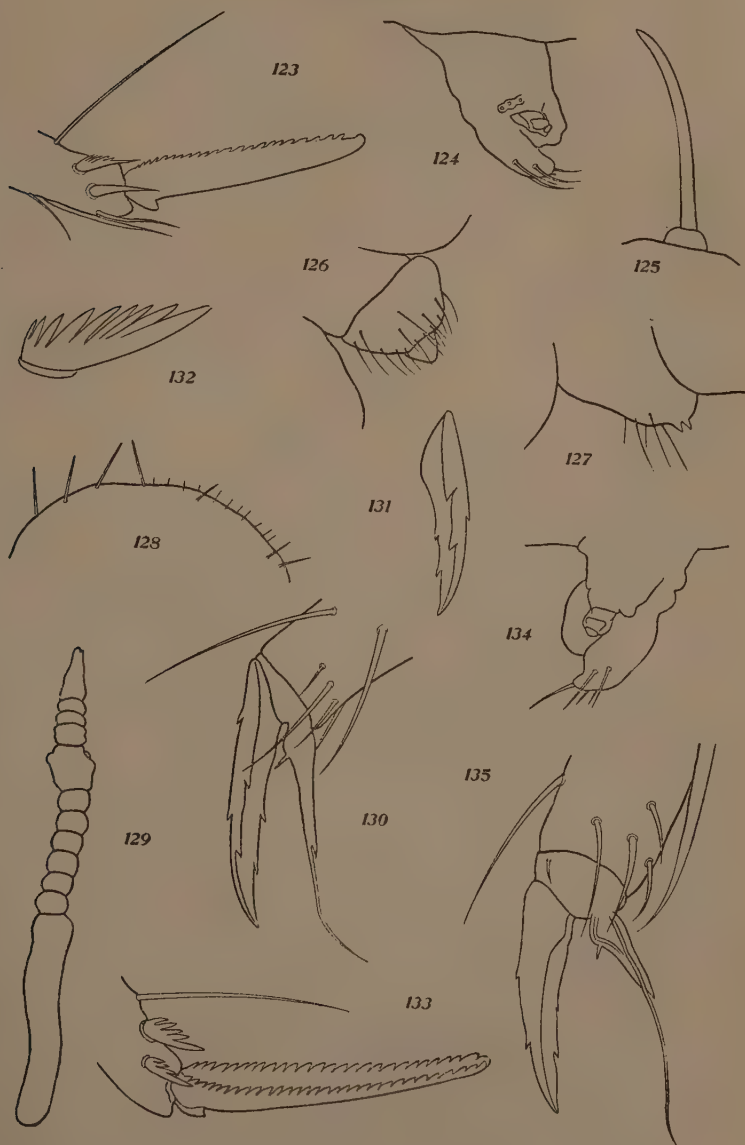
PLATE XV

Ptenothrix texensis (Packard)

Fig. 136.   Serrate setae of dens.

Fig. 137.   Dorsal aspect of left mucro.

Ptenothrix marmorata (Packard)

Fig. 138.   Eyes of right side.

Fig. 139.   Right hind foot.

Fig. 140.   Serrate seta from dens.

Fig. 141.   Serrate seta from dens.

Fig. 142.   Left mucro.

Fig. 143.   Subanal appendage of female.

PLATO XV

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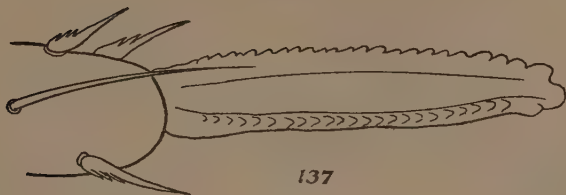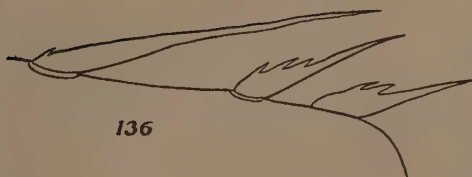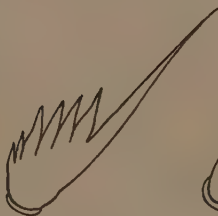
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PLATE XVI

PLATE XVI

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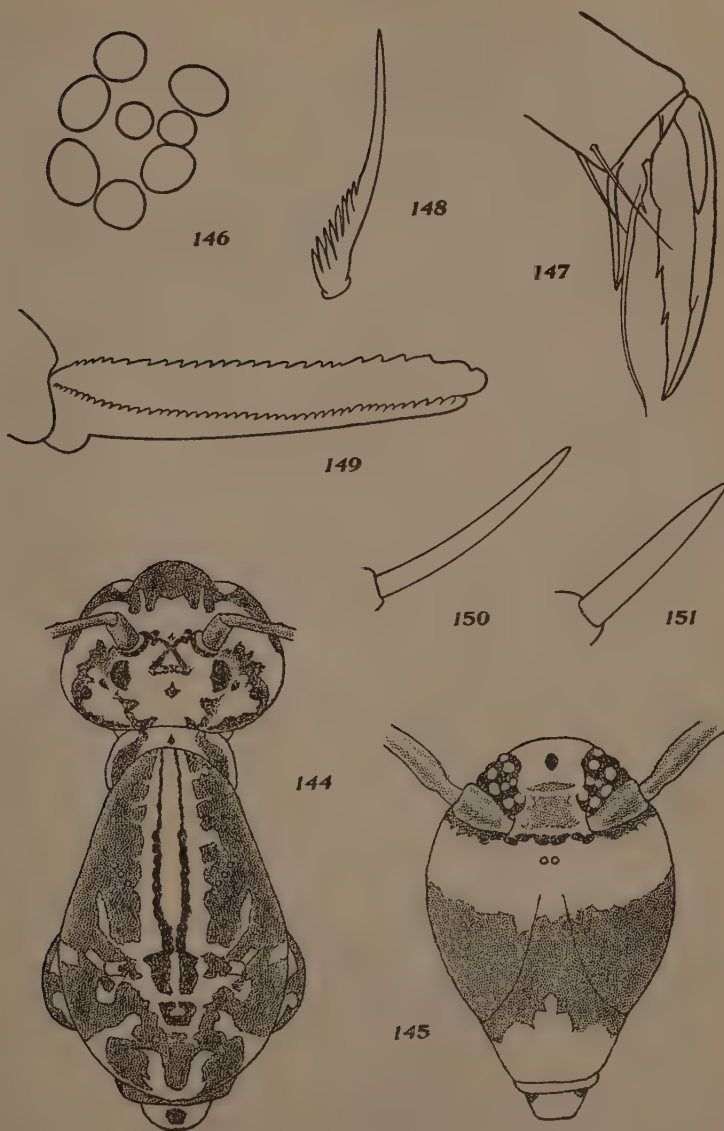
OBSERVATIONS ON HEXAMITA MARMOTAE N. SP., A PROTO-
ZOAN FLAGELLATE FROM THE WOODCHUCK
MARMOTA MONAX (LINN.)

H. B. CROUCH[1]

Octoflagellates morphologically similar to the species to be described
in the following paragraphs have been placed by various writers in two
different genera, *Hexamita* and *Octomitus*. The genus *Hexamita* was
created by Dujardin (1841) to include three species of bilaterally sym-
metrical flagellates, one parasitic in the frog and two free-living. In his
descriptions he observed only six flagella in each species. Grassi (1879)
pointed out that the parasitic form had six anterior and two posterior
flagella. Prowazek (1904) proposed the genus *Octomitus* to include an
octoflagellate he observed in rats. The life history of this flagellate was
studied by Wenyon (1907), and he decided that it should be placed in the
genus *Hexamita*. The history of this question of long standing has been
discussed at length by Dobell (1909), Wenyon (1926) and others. It is
now generally agreed that one of these names should become a synonym,
since they both represent the same group of flagellates. Since it is evident
that Dujardin was observing members of this same group of flagellates
when he established the genus *Hexamita,* it appears that *Octomitus* is in-
valid, as was pointed out by Wenyon (1926) and by Wenrich (1933). The
·writer, therefore, provisionally places this new flagellate from the wood-
chuck in the genus *Hexamita*.

Relatively few species of *Hexamita* have been reported from a variety
of invertebrate and vertebrate hosts. *H. muris* (Grassi, 1881) from rats,
mice and other small rodents has been observed by many writers. Becker
(1926) described *H. pulchra* from the striped ground squirrel (*Citellus
tridecemlineatus*). Da Cunha and Muniz (1929) described *Octomitus
(Hexamita?) pitheca* from monkeys (*Macacus rhesus*) imported into
Brazil. Wenrich (1933) in Philadelphia, observed what was probably a
different species from the same host. Recently Bishop (1933) described
the morphology and division of *Hexamita gigas* from the hind gut of the
horse leech.

The material for this observation was collected from the caeca of fifteen
woodchucks obtained near Ames, Iowa, over a period of two years. Seventy-
five per cent of the woodchucks examined harbored the flagellate described
in this study along with other flagellates previously described by the writer
(1933). In no case was the species here described found in great numbers.

For more detailed studies, smears were fixed in Schaudinn's fluid and
stained by the Heidenhain's iron-haematoxylin method.

Hexamita marmotae n. sp.

In the living condition, the anterior flagella create such a disturbance

in the medium by their motion that it is very difficult to determine many morphological structures. The general shape of the body is about the same in both living and stained specimens. It is from ellipsoidal to egg-shaped, being broad at the anterior end and tapering bluntly toward the posterior end. Through its greatest dimensions, the body is about one-third longer than it is wide. The greatest width diameter is through the anterior one-third of the body. Measurements of one hundred stained specimens, picked at random over several slides from different hosts, give a length range of 4.5μ to 9μ, and a width range of 3.5μ to 7μ. The mean derived from this distribution gives an average of 6.71μ by 5.28μ. It is interesting to note that the mean size of these flagellates varies in different hosts.

TABLE I. *Correlation table of one hundred stained trophozoites of Hexamita marmotae, n. sp.*

Width in microns	Length in microns										
	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	Total
3.5	1			1							2
4.0		1	1	3	1						6
4.5		2	1	2	3	1					9
5.0	1	3	3	3	14	11	1	2			38
5.5				1	8	6	5	2			22
6.0					6	2	2	2	1		13
6.5						1	3	1	1		6
7.0								1	1	2	4
Total	2	6	5	10	32	21	11	8	3	2	100

	Length	Width
Mean	6.71μ	5.28μ
Range	4.5μ —9.0μ	3.5μ —7.0μ

The cytoplasm is highly vacuolated, some of the vacuoles being very large. The cytoplasmic content stains very deeply at the extreme anterior end of the body. This highly granular material almost entirely surrounds the two nuclei in most specimens. The two anterior blepharoplasts are also embedded in it. They are about a micron apart near the anterior margin of the body. A flagellum about the length of the body arises from each of these granules. Just posterior to and between these two basal granules there is a centrally located granule. It is closely associated with the two nuclear membranes, and seems to form a division line between them at this point. No organelles are seen to arise from this granule. The second pair of granules is located at the base of the two nuclei, near the anterior terminations of the axostyles. A pair of flagella arises from each of these blepharoplasts. One pair is usually directed backward over the body, while the other pair is usually directed to the side and then backward. Two axostyles originate on each side of the median line of the body near

the base of the nuclei. They appear to arise from the second pair of basal granules, but this is not clear in any specimens observed. There is little reason to believe that this flagellate has true axostylar filaments, as there is no encasement membrane observable at any place along the two rows of siderophilic granules. These two filaments approach each other at acute angles, and come in contact a short distance from their origins. This contact is maintained through the cytoplasm to a point near their posterior terminations. Then they bifurcate very much in the same fashion that they come together at the anterior end of the body. These axostyles maintain this close contact in all specimens observed. This double filament is very plastic and may be curved in various manners (Fig. 3). Each horn of this double filament terminates at the posterior margin of the body. There is no protruding axostyle beyond the posterior end of the body as observed by many writers in other species. A posteriorly directed flagellum arises from a group of deeply stained granules near the termination of each axostyle.

When specimens are observed from a different plane, the axostyles may appear as one solid mass of siderophilic granules (Fig. 4). The two nuclei are difficult to see in most specimens due to the granular mass that almost surrounds them. They are oval bodies with their anterior margins in contact (Figs. 1 and 2). The second pair of basal granules is either within the nuclei, or adhering very closely to the nuclear membranes. These two granules look like eccentric karyosomes. It can clearly be seen, however, that one pair of flagella arises from each of them. Alexeieff (1911) observed this condition in *Hexamita* (*Octomitus*) *intestinalis* and suggested that the bodies may be intra-nuclear organelles.

No cytostome has been observed, although many of the vacuoles contain food material. The body is very plastic but not amoeboid. No cysts have been observed.

DISCUSSION

Even though *Hexamita muris* is found in a variety of rodent hosts, it can easily be differentiated from the species just described. The size range cannot be used as a differentiating character, as Wenyon (1907) found the size range to be from 4 μ to 10 μ in *H. muris*. The nuclei are comparatively large and the axostyles traverse different paths through the cytoplasm. On the other hand, the nuclei are somewhat smaller, and the axostyles traverse the same path most of the length of the body in the *Hexamita* from the woodchuck. These differences provide reasons to believe that they are not the same species.

The writer is greatly indebted to Dr. E. R. Becker for the opportunity of making comparative studies from the original preparations of *Hexamita pulchra*. This flagellate measures from 8 μ to 10 μ by 6 μ or 7 μ, thus being somewhat larger than the average of 6.71 μ by 5.28 μ found in the species described here. The granular cytoplasm is contrasted with the heavily vacuolated cytoplasm of *H. marmotae*. The central basal granule between the nuclei, and also the posterior granules from which the trailing flagella arise are absent in *H. pulchra*. The axostyle terminates at the body membrane in *H. marmotae*, while it protrudes beyond the body membrane in *H. pulchra*. Other minor differences can be seen between the two species when they are studied together. In all, this flagellate seems to possess enough individuality to warrant the establishment of a new species.

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SUMMARY

Hexamita marmotae, n. sp., from the caecum of the woodchuck *Marmota monax* (Linn), has a size range from 4.5 μ to 9 μ by 3.5 μ to 7 μ, with an average of 6.71 μ by 5.28 μ. The body is ellipsoidal to egg-shape, with its greatest diameter through the anterior one-third of the body. Six anterior flagella arise from four blepharoplasts. A fifth blepharoplast between the nuclei has no organelles. The nuclei are oval and meet at their anterior ends. They appear to contain the second pair of basal granules from which the paired flagella arise. The axostyles traverse the most of the body as one continuous filament, and do not protrude beyond the posterior end of the body. The posterior pair of flagella arises from a pair of basal granules on the axostyles. In all, there are seven blepharoplasts, eight flagella, two nuclei and two axostyles. Solid food material is found in some of the vacuoles, although no cytostome is observed.

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PLATE I

Fig. 1 Trophozoite with nuclei partially hidden under the anterior granular area.
Fig. 2 Trophozoite showing central basal granule and abnormal appearance of the base of the axostyles due to orientation within the cytoplasm.
Fig. 3 Trophozoite with axostyles curved at the base.
Fig. 4 Lateral view of trophozoite showing a basal granule and the axostyles as a single mass.

PLATE I
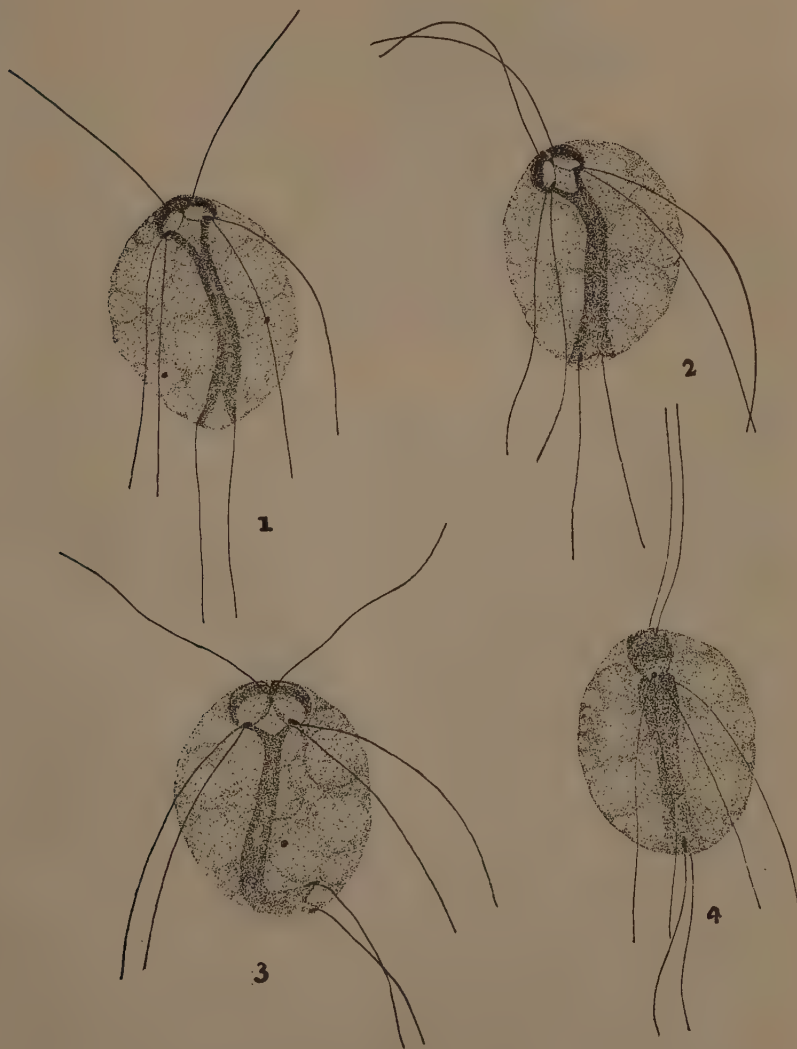
AN ENTOMOTOGRAPH, AN INSTRUMENT FOR RECORDING THE APPENDICULAR OR LOCOMOTOR ACTIVITY OF INSECTS

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The entomotograph[1] is an instrument devised by the authors for the purpose of recording graphically the appendicular activity of insects and the effects of various applied stimuli, especially chemical, upon the insect's neuromotor activity. Although the insect used in this investigation was the nymphal or imaginal form of the large roach *Periplaneta americana* L., the apparatus may be adapted to the use of many other insect species, in nymphal, larval or imaginal form.

The instrument (Pl. I). The apparatus embodies the idea of a wheel revolving in a vertical plane with a pointer recording upon a moving smoked drum. A light aluminum wheel (W) revolves on a horizontal axle (A), held by a support (S) which is itself fastened to a rectangular, wooden support (WS). The wheel carries a light weight pointer (P), made of balsa wood and tipped with a writing point (T), made of photographic film (negative) or kymograph paper; when the wheel is at rest, the pointer is horizontal. The upper arc of the wheel's rim supports a running tread (Tr), upon which the animal's feet rest. The insect (I) is fixed to an animal holder (H) by four threads that encircle the body at the divisions between head and thorax, the thoracic segments and thorax and abdomen; after passing around the body these threads are held fixed with a little soft wax pressed against the arm (Am) of the holder. In the initial experiments, the terga of the animals were cemented to the holder with rubber cement, but this procedure was later discarded in favor of threads as the rubber cement appeared to have some effect upon the activity record. The base (B) of the holder is fastened to the wooden support with soft wax in such position that the insect is supported at the proper distance above the running tread (Tr) with which its feet make contact. Any locomotor activity of the insect thus results in a movement of the pointer (P), the tip of which moves upward as the animal tries to walk forward and moves downward as the animal attempts to walk backward. Two springs (1 and 2) extend from the screws (S_1 and S_2, respectively) to the end of a vertical pin (VP) and oppose respectively the upward and downward movements of the pointer, caused by the animal. The axle (A) and vertical pin (VP) are supported by an aluminum strip (D_1, D_2) that extends along the horizontal diameter of the wheel at rest, the range of movement of which is limited by contacts between D_1 and the screw S_1 and between D_2 and S_2. The entire apparatus is held by a burette clamp (C) which is in turn clamped to the rod (R) of an iron supporting stand. As the pointer moves, due to the activity of the insect, its tip (T) leaves a record on the smoked surface of a long strip of kymograph paper, supported on two spring kymo-

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[1] This name was suggested by Mr. Oscar E. Tauber of this department.

graphs, not shown in Plate I, one of which is permitted to rotate, slowly moving the paper.

The instrument can be calibrated by attaching a thread to the wheel, at C_1 or at C_2, and suspending by it weights of known value. For example, no weight is attached to the thread and a base line (BL, Pl. II) is recorded on the smoked paper; then a five gram weight is attached at C_2 and another line is recorded, showing the height to which the lever tip will rise when the wheel is pulled with a weight of five grams; similarly, other calibration lines can be made with other weights or calibration may be in terms of the extent of pointer rise or fall in millimeters above or below the base line. In this way, the force which the insect exerts upon the wheel is measured by the vertical distance through which the pointer tip moves, while the appendicular activity of the animal is recorded as oscillations of the pointer.

The running tread used with the roach, *P. americana* L., consists of sandpaper of medium coarseness. This gives the animal a suitable gripping surface but does not allow the tarsal hooks to become caught and passively held, as may occur with a cheese cloth surface. The sandpaper tread is held by soft wax upon a cardboard support which is in turn fixed with wax to the rim of the wheel.

This apparatus may be adapted to various species of insects, in larval, nymphal or imaginal states, by varying the nature of the running surface, the size and "elasticity" of the springs (1 and 2) which oppose the pull exerted by the insect and the sizes and forms of the animal holder and wheel.

METHOD

With this apparatus the activity of the insect can be recorded under a variety of experimental conditions. The present preliminary experiments have been concerned especially with the effects of certain exciting, depressing or noxious liquids upon the insect's activity. The test substances were placed directly upon the animal's abdominal exoskeleton. In each experiment the animal was arranged in the manner just described and a short record of normal activity recorded. At a given time, a known number of drops of the test liquid were placed upon the abdominal exoskeleton. A comparison of the record before and after applying the test liquid showed the effect of the substance. In addition, lengthy activity records were obtained from normal, untreated animals. As a rule, the final kymograph record shows the base and calibration lines (if any), the record of the insect's activity changes (entomotogram) and a time record in minutes made by a recording chronometer (not shown in Pl. I).

RESULTS

A number of preliminary experiments have been made to determine the appearance of the record of normal activity as affected by the application of one or two drops of acetone, benzol and other substances, some of which were applied as acetone or benzol solutions; of the various substances tested, only the results of acetone and benzol will be given here for illustration purposes.

(a) NORMAL ACTIVITY

Portions of typical records of normal activity are shown in Plate II, N_A and N_B. When the record is taken immediately after the animal is

fixed to the holder, it is characterized by an initial period of appendicular activity, caused apparently by the excitement due to handling; this is followed by a prolonged period during which the animal tends to exert a pull on the wheel causing the pointer to remain in general above the base line, although this is varied by sharp rises (r) of the pointer, due to attempts of the insect to walk forward, and sudden falls (f) of the pointer to the base line or below it, due to attempts of the insect to walk backward; for the most part, however, the pointer tends to remain above the base line, as at i. The animals used exerted an average normal pull of approximately 5 grams. The initial activity tends to become gradually less, the record showing less frequent outbursts of activity (o), separated by longer periods of inactivity (i), during which the pointer is held above the base line. There are, of course, individual variations among the records from different individuals, some tending to be more or less active than others, but, as a rule, the normal record is quite recognizable and reproducable. The normal active roach seldom holds the lever at or below the base line but persistently tends to move forward.

(b) THE EFFECT OF ACETONE

Plate II, A, is a part of a record from an animal treated with a drop of acetone. It is apparent that one drop of acetone applied to the insect's abdominal body surface has only a negligible effect upon activity.

(c) THE EFFECT OF BENZOL

Plate II, B_1, B_2 and B_3, are taken from a record made by an animal treated similarly with one drop of benzol, the application of which to the abdominal exoskeleton produces an immediate and marked effect. The forward pull of the animal, holding the pointer above the base line, is suddenly decreased. The pointer then continues to show oscillations of limited amplitude at or close to the base line (see B_1) for a considerable time. These persistent oscillations are produced by an unorganized but continued activity of the animal's appendages, which move actively in an uncoordinated, abnormal manner. The amplitude of oscillation eventually becomes less (see B_2) and less (see B_3) until the insect is quiescent.

DISCUSSION

With this device it is possible to obtain graphic records of the appendicular or locomotor activity of different larval, nymphal and imaginal insects as well as the effects upon activity of various chemical substances. In the present studies, in which only large nymphal and imaginal roaches were used, it has been shown that acetone, which can be used as a solvent for certain organic compounds, has an inappreciable effect when one drop of it is applied to the animal's body surface while, on the other hand, benzol, similarly applied, produces a marked effect. Of these two liquids, acetone is obviously the more suitable for use as a solvent for certain excitant or depressant substances whose effects upon *P. americana* are to be studied.

On the basis of preliminary experiments which have been made, it is suggested that this method may be found of use in the field of insect toxicology; it is not impossible that a method of this type may become of use to applied entomologists from the standpoint of bio-assay or as a method for testing the effectiveness of certain chemical compounds or insecticides.

SUMMARY AND CONCLUSIONS

(1)   An instrument, called entomotograph, has been devised for the purpose of recording the appendicular and locomotor activity of larval, nymphal and imaginal insects; by calibration the force exerted by the insect can be measured in grams or dynes.

(2)   With this instrument it is possible to record graphically the effects on activity of various chemical substances applied to the animal's body.

(3)   It has been shown that the entomotogram of the normal roach, *P. americana* L., (large nymphs and adults) is quite recognizable and reproducible.

(4)   The marked effects of applying one drop of benzol to the insect's abdominal exoskeleton have been demonstrated.

(5)   It has been shown that the application of one drop of acetone to the insect's abdominal exoskeleton is without appreciable effect and that, therefore, acetone may be used as a solvent in solutions of certain organic compounds applied in this way.

(6)   It is suggested that this method may be of use to insect toxicologists, applied entomologists and other investigators in the field of insect control who are interested in the effects of chemical compounds upon insect activity.

PLATE I, Fig. 1

Photograph of the entomotograph, an apparatus for registering graphically the appendicular and locomotor activity of the larval, nymphal or imaginal insect. See text.

PLATE I

Fig. I.

PLATE II

Entomotograms of *P. americana* L. nymphs, showing normal activity (N_A, N_B), the negligable effect of acetone (A) and the marked effect of benzol (B), applied to the abdominal exoskeleton. The time record (t) is in minutes; the tips of the minute marks have been emphasized with white ink. BL is the base line. In B_1, the benzol was applied just before the arrow, the effect being recorded immediately.

PLATE II
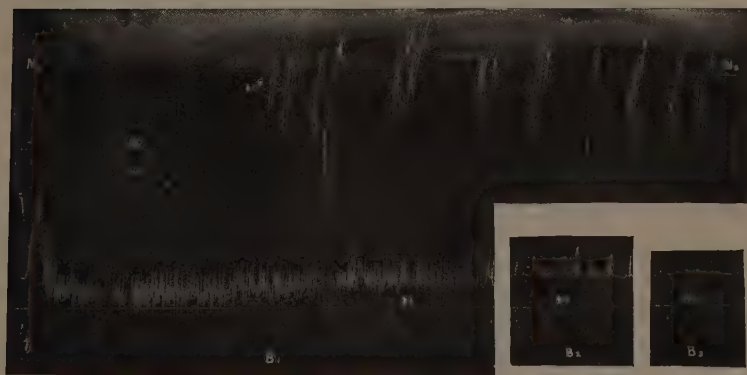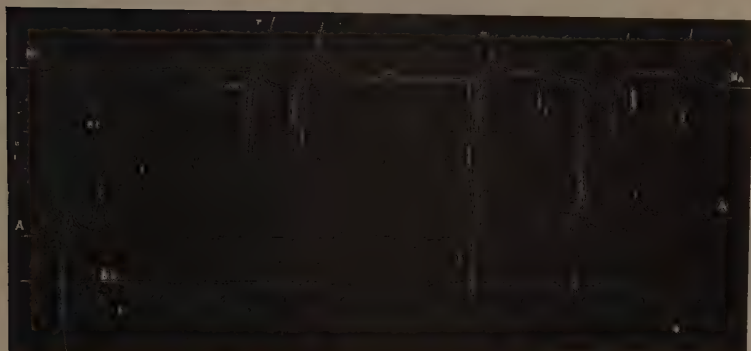
TRYPANOSOMA IOWENSIS N. SP. AND BABESIA CITELLI N. SP. FROM CITELLUS TRIDECEMLINEATUS, AND TRYP- ANOSOMA HIXSONI N. SP. FROM CITELLUS FRANKLINI[1]

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The striped ground squirrel (*Citellus tridecemlineatus*) has been shown to harbor in its digestive tract the following species of protozoan parasites: *Endamoeba citelli* Becker, 1926, *Chilomastix magna* Becker, 1926, *Trichomonas* sp., *Tetratrichomastix citelli* Becker, 1926; *Hexamita pulchra* Becker, 1926, *Giardia beckeri* Hegner, 1926 and *Eimeria citelli* Kartchner and Becker, 1930. More recent investigations of the blood of the same host have disclosed the occasional presence of *Trypanosoma iowensis* n. sp. and *Babesia citelli* n. sp. A trypanosome, *T. hixsoni*, was also found in the blood of *Citellus franklini*, Franklin's ground squirrel. The two species of trypanosomes were first discovered by Mr. Homer Hixson, who was kind enough to transfer his interests in the problem to the writers when he was prevented for the present from continuing his studies.

Trypanosoma iowensis n. sp.

(Plate I, fig. c-g)

This trypanosome was present in the blood of two out of 84 striped ground squirrels captured in the vicinity of Ames, Iowa, during the summer of 1933. Fifty specimens in blood smears stained with Wright's stain, from one of the captured squirrels, measure from 24.0 µ to 29.0 µ in total length from 1.2 µ to 2.0 µ in breadth; mean size, 26.3 µ by 1.6 µ.

The nucleus in most instances is located on the side away from the undulating membrane, with its long axis in the direction of that of the body; average size, 2.3 µ by 1.0 µ. The parabasal body is deeply staining and fusiform in shape, with the long axis transverse to that of the body. Its length is approximately equal to the breadth of the body at the level where it is located. The undulating membrane is only moderately developed, but slightly more than in *Trypanosoma lewisi*. The cytoplasm is in general quite homogeneous, but sometimes there is a vacuole-like, lightly staining area in front of the parabasal body (Pl. I, fig. d). The posterior end of the body tapers rapidly to a sharp point. The marginal flagellum of the undulating membrane extends forward beyond the anterior end of the body from 6.2 µ to 9.7 µ.

The trypanosome is of the so-called *T. lewisi*-type, but differs from this species in respect to certain of its measurements. According to Taliaferro (1921), *T. lewisi* in the adult stage has the following measurements: (1) posterior tip to parabasal body, 4.268 µ; (2) parabasal body to middle of nucleus, 10.854 µ; (3) middle of nucleus to anterior end, 9.511 µ; (4) anterior end to tip of free flagellum, 6.619 µ; (5) total length, 31.251 µ. The same for *T. iowensis* are: (1) 2.4 µ; (2) 9.3 µ; (3) 7.0 µ; (4) 8.0 µ; (5) 26.3 µ. Thus it is evident that the posterior snout of the body is markedly

shorter than in *T. lewisi*, the free flagellum is somewhat longer, and the entire body length is considerably less.

It is very difficult to evaluate the possible relationship between the trypanosome of *Citellus tridecemlineatus* and trypanosomes which have been described from other ground squirrels. Some of the latter are *T. spermophili* originally described by Laveran, 1911 from *Citellus musicus, C. guttatus* and *C. eversmanni*, but since reported by other authors as occurring also in *C. mugozaricus, C. fulvus, C. suslica* and *C. pygmaeus,* all Old World forms (*V.* Sassuchin, 1931). So far as the literature is available to us, we have not been able to find any measurements recorded for the parasite in any of these hosts, even in Laveran's original brief description. Sassuchin published a photo-micrograph of one specimen which resembles *T. iowensis,* but it is of course impossible to tell very much about a species from one specimen. Tartatowsky (1913) described *T. schalaschnikovi* from *C. guttatus,* but his original description is not available to us. Wellman and Wherry (1910) described *T. otospermophili* from *C. beecheyi*, the California ground squirrel. The measurements submitted for this flagellate agree very closely with those for *T. iowensis*. Another trypanosome which has been described from ground squirrels is *T. citelli* Watson, 1912 from *Citellus richardsoni* collected in Alberta, Canada. The length of this form is stated to be 35 μ, which is beyond the 32.5 μ for the largest specimen of *T. iowensis* seen by us.

Thus, while our trypanosome closely resembles *T. spermophili* and *T. otospermophili,* it is impossible to identify it positively with either of them. The absence of differential structural characters often makes the identification of trypanosomes on the basis of morphology alone impossible. From the almost universally negative results from cross-infection experiments with trypanosomes of the *T. lewisi*—type, it is almost a safe generalization to say that they show a rather rigid host-specificity, and that each species of host has its own kind. Our failure to infect *Citellus tridecemlineatus* with a trypanosome occurring naturally in *C. franklini* is further support of this generalization.

The intermediate host for *T. iowensis* is a flea, probably *Rostropsylla bruneri*. The fleas were raised in the laboratory from the egg to the adult stage, and the adults had not fed on any animal except *Citellus tridecemlineatus*. The adult fleas were kept in a tight cage with the infected squirrels for thirty days before their intestines were removed and dropped into fixing fluid. The metacyclic trypanosomes were found in great numbers attached to the wall of one of the sectioned rectums.

The pathogenicity of this trypanosome is in doubt. The writers thought at first that it was pathogenic, because some of the squirrels inoculated with blood containing the trypanosomes from one of the captured infected squirrels died within seven to eighteen days after the date of inoculation. Some of the squirrels, however, harbored the trypanosomes for as long as five months without any apparent ill effects. Furthermore, some of the uninjected and apparently trypanosome-free squirrels died in their cages with symptoms similar to those in the inoculated squirrels. The malady was characterized by posterior paresis and injected cerebra, so it seems likely that in the summer of 1933 there was a disease-producing virus of nontrypanosome nature attacking ground squirrels in this region. It should be mentioned that in no squirrel examined by us, either naturally or artificially inoculated, were the trypanosomes numerous.

Two white rats inoculated with blood containing this trypanosome did not become infected.

Trypanosoma hixsoni n. sp.

(Plate I, fig. a, b)

This trypanosome was present in small numbers over a period of almost three months in the blood of a Franklin's ground squirrel captured near Ames, Iowa. It is also of the *T. lewisi* type, but differs in two important respects from *T. iowensis*. First, it is longer, measuring 26.0 μ to 34.8 μ in length, with a mean size of 32.0 μ by 1.6 μ. Other measurements are as follows: posterior end to parabasal body, 3.4 μ; parabasal body to nucleus, 9.8 μ; nucleus to anterior end, 7.5 μ; anterior end to end of free flagellum, 10.9 μ. Second, the parabasal body is larger, being much more rounded than in *T. iowensis*. Of all the trypanosomes recorded from ground squirrels (*vide supra*), this species resembles most *T. citelli* Watson, 1912 from *Citellus richardsoni*. As was previously stated, *T. hixsoni* did not prove to be infective to *Citellus tridecemlineatus*. The refractive squirrels were later successfully infected with *T. iowensis*, however.

We take great pleasure in naming this protozoan after its discoverer, Mr. Homer Hixson.

Babesia citelli n. sp.

(Plate II, fig. a-l)

In blood smears from two out of eighty-four ground squirrels captured during the summer of 1933 were noted red cells parasitized with a protozoon of the genus Babesia. So far as it was possible to ascertain, only one species of this genus has previously been described from ground squirrels; viz., *Babesia* (*Piroplasma*) *kolzovi* Sassuchin, 1931, from *Citellus pygmaeus* the steppe squirrel of southeastern Russia. The most typical forms of the latter species are the pear-shaped individuals which are slightly longer than the radius of the parasitized red cell. These often occur a pair in a red cell, with the individuals meeting by their more pointed ends at an acute angle. Single amoeboid forms in the peripheral blood and pyriform individuals to the number of three to sixteen in a red cell in the internal organs were also encountered.

Babesia citelli differs from *B. kolzovi* in a number of important respects. First, the "bigeminous" pear-shaped individuals either do not occur, or were so rare that none of them were encountered during the study. Second, the predominating forms are large and small rings (Pl. II, fig. a, b, f, i) which were not mentioned for *B. kolzovi*. Third, narrow band-like forms extending all or most of the way across the red cell are numerous (Pl. II, fig. d, j).

The ring forms measure 1.0 μ to 2.5 μ across. Most of them have double nuclei in close proximity to each other (Pl. II, fig. a, f), though some have but a single nucleus (Pl. II, fig. b). The narrow bands were generally tapering toward one end and blunt at the other, with the nucleus closer to the more tapering end. Their nuclei were more or less elongate. Occasional large pear-shaped (Pl. II, fig. c), large, thick, rod-shaped (Pl. II, fig. k) and large, racket-shaped (Pl. II, fig. h) individuals were also seen. Such forms usually had a compact nucleus at or near one margin and a vacuole adjoining the nucleus. Rarer forms are minute, deeply staining dots of nuclei from which flare one or two strands of protoplasm (Pl. II, fig. g)

and amoeboid forms with a prominent nucleus at one end and next to a vacuole (Pl. II, fig. e). In general the parasitized red cells were of normal size, but one much larger was seen (Pl. II, fig. l). This curious cell contained two enormously enlarged parasites, one of them with three nuclei. Perhaps the latter individual was in the process of division.

The Babesia parasites were numerous in the blood of the ground squirrels. The infected animals were noticeably anemic, for the blood was thin and the red cells were scarce in the blood smears. The two infected squirrels died, but it cannot be safely assumed that their death was due to the Babesia (though it probably was!) for, as previously stated, some of the squirrels seemed to have a virus disease.

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DESCRIPTION OF FIGURES

Plate I, (a and b, X2208; c-g, X2860)

a and b	*Trypanosoma hixsoni.*
c—g	*Trypanosoma iowensis.*
f	*T. iowensis* dividing.
g	*T. iowensis* crithidiamorphic form from ground squirrel blood.

Plate II. (X2860)

a—l	*Babesia citelli.*
a, b, f, and i	Ring stages; i showing division.
c	Pear-shaped form.
d and j	Band-like forms.
e	Amoeboid form.
g	Nucleus with two strands of cytoplasm.
h	Racket-shaped form.
k	Rod-like form.
l	Enlarged red cell containing two parasites.

PLATES I AND II

Pl. I.
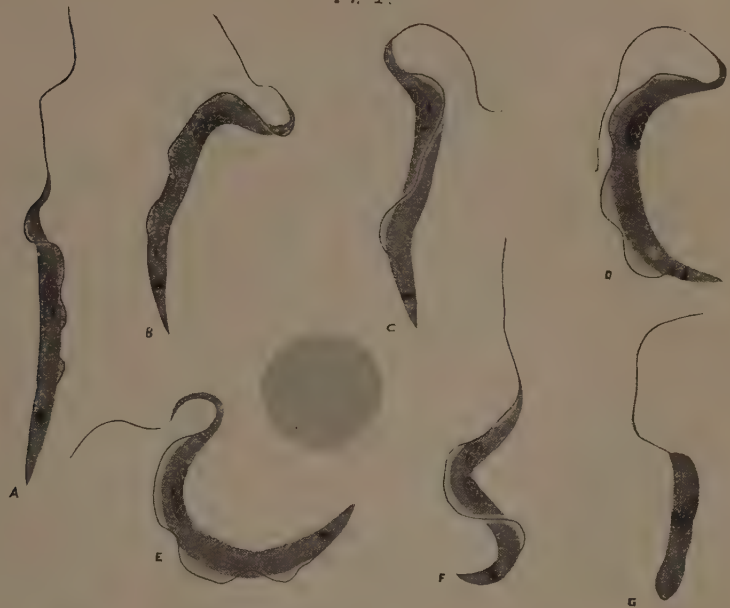
Pl. II.
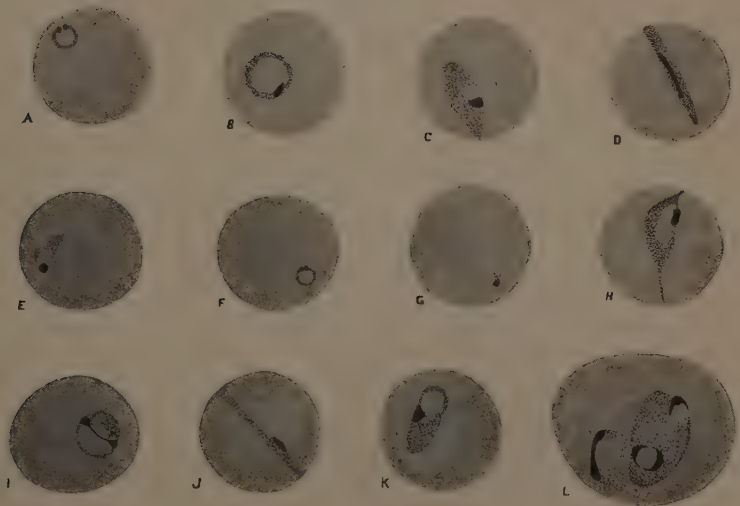
THE DEVELOPMENT OF TRYPANOSOMA IOWENSIS IN THE BLOOD OF THE STRIPED GROUND SQUIRREL, CITELLUS TRIDECEMLINEATUS[1]

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Trypanosoma iowensis, which has been described by the writers (1934), inhabits the blood stream of *Citellus tridecemlineatus,* the common striped ground squirrel. The intermediate host is a flea for, as described by the writers in the aforementioned article, the development to the metacyclic or infective stage was found to occur in this invertebrate. The present study was initiated for the purpose of comparing the cycle in the blood of the ground squirrel with that of *T. lewisi* in the rat.

The life-cycle of *T. lewisi* in the rat has been described both biometrically and graphically by Taliaferro (1921, 1926) and Taliaferro and Taliaferro (1922). The latter authors have stated that the course of the infection is as follows: First, there is a prepatent period of from four to eight days during which no organisms are found in the blood. Then follows a multiplicative period of variable length during which the number of trypanosomes may reach a half million or less per cmm. of blood. The multiplicative period is climaxed by a precipitous drop in numbers of trpanosomes, but a moderate number continue to inhabit the blood over a period of from seven to one hundred days (''adult'' infection). At the end of the latter period no more flagellates can be found in the rat's blood.

During the multiplicative period the coefficient of variation for the length of the rapidly dividing individuals was high, but this statistical constant dropped steadily from slightly over 25 per cent on the day of the first appearance of the microörganism in the blood to less than four per cent on the tenth day. The coefficient of variation varied somewhat, but remained low throughout the period of the ''adult'' infection.

In our study we encountered several discouraging conditions. In the first place, we spent an enormous amount of labor in capturing ground squirrels before an infected individual was captured late in the summer. The eighty-fourth squirrel examined was the first individual from which we could obtain the microörganism. In the second place, this infected squirrel was evidently harboring a virulent virus, for large numbers of young ground squirrels inoculated by direct transfer of blood from it died within from one to ten days later, many of them before the appearance of trypanosomes in their blood. Thus many of our attempted studies were brought to an untimely end. Third, several adult squirrels were refractory to infection. And fourth, the numbers of trypanosomes in the blood during the infection were always extremely sparse, and locating 50 specimens for measurement each day during the infection was an extremely time-consuming process. For this reason also it was impracticable to attempt any counts

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on the numbers of trypanosomes per cmm. of blood. As a matter of fact, out of 800 trypanosomes actually measured, only three showed evidences of division such as dividing parabasal body, development of a new flagellum, or double nuclei. A biometric study was made on the trypanosomes from three ground squirrels. The basis for the measurements was camera lucida drawings of trypanosomes in dried smears stained according to Wright.

Fifty trypanosomes from one squirrel were measured three days after the host was captured and two days after the flagellates were found in the blood. Of course it was not known of how long standing the infection had been previous to the date of measurement. The measurements showed a length of 24.0 μ to 29.0 μ and a breadth of 1.2 μ to 2.0 μ; mean size, 26.3 μ by 1.6μ; coefficient of variation for length, 7.22 per cent.

A young ground squirrel, whose blood had been found to be free of trypanosomes for three successive days, was injected intraperitoneally with about 0.25 c.c. of blood from the above-mentioned squirrel. The trypanosomes first appeared in the blood on the eighth day. The animal died on the twelfth day, but the cause of death was undetermined. Fifty trypanosomes were located with difficulty each day and measured. The mean lengths of the trypanosomes for the five days for which the measurements were made were (1) 24.59 μ, (2) 24.25 μ, (3) 25.81 μ, (4) 25.41 μ, (5) 26.10 μ, respectively. The coefficients of variation for the different days were (1) 7.80 per cent, (2) 7.91 per cent, (3) 6.14 per cent, (4) 7.27 per cent, and (5) 5.87 per cent, respectively.

Another squirrel was injected intraperitoneally with 0.25 c.c. of blood from the same squirrel as the preceding. The trypanosomes first appeared in the blood on the tenth day and continued to do so for nine more days, at which time death from some unknown cause occurred. Fifty trypanosomes were located each day of the infection with difficulty, and then measured. The average lengths by days were as follows: (1) 26.19 μ, (2) 26.05 μ, (3) 26.39 μ, (4) 27.10 μ, (5) 27.51 μ, (6) 27.82 μ (7) 26.70 μ, (8) 26.54 μ, (9) 28.08 μ, (10) 28.19 μ. The coefficient of variation by days were as follows: (1) 5.86 per cent, (2) 6.35 per cent, (3) 6.15 per cent, (4) 9.07 per cent, (5) 6.18 per cent, (6) 6.35 per cent, (7) 6.64 per cent, (8) 8.07 per cent, (9) 6.12 per cent, (10) 5.04 per cent.

In the case of these two inoculated squirrels, the trypanosomes were rare in the blood at all times, but it was apparent that in both they increased steadily in numbers for the first five days after their appearance in the blood. The first squirrel died at the end of the fifth day, but the numbers gradually decreased in the other squirrel until they could be found only with the greatest difficulty on the morning of the tenth day, when it died.

It is clear that the development of *T. iowensis* in the blood of the striped ground squirrel shows little resemblance to that of *T. lewisi* in the blood of the rat. The prepatent period being longer, there is no initial rise in numbers to an impressive peak and then a sharp reduction. Furthermore, trypanosomes show scant variation in mean length from day to day, and the coefficient of variation shows no significant difference at the beginning of the infection from that five or ten days later. Evidently reproduction progresses slowly, and the host builds up a resistance before any great numerical increase can take place. In fact, as was already mentioned, three adult squirrels proved to be completely refractory to inoculation.

It is certain that all infections do not terminate fatally and that many

infections are of long duration. One squirrel harbored a light infection for almost five months, but later lost it. This squirrel, which was last examined about four months before the present writing, is still alive (March 19, 1934) but apparently free from trypanosomes.

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THREE NEW TRICHOMONADS FROM BIRDS[1]

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Hardly more than a dozen species of the genus Trichomonas have been described from avian hosts. Of these, seven have been described from the order Galliformes. From many orders, however, not a single species of this genus has been taken. Two new species presented in this paper, are from a night-hawk, *Chordeiles minor* (Forster), of the order Caprimulgiformes, and one from three species of sandpipers, least sandpiper, *Pisobia minutilla* (Vieillot), pectoral sandpiper, *Pisobia melanotos* (Vieillot), and the semipalmated sandpiper, *Ereunetes pusillus* (Linnaeus), all of the order Charadriiformes.

During the summer of 1933, in connection with the Wild Life studies for Iowa State College, many opportunities for parasitic examination were encountered. Smears of intestinal material were examined both while the parasites were still active and in stained preparations. The material was fixed in Schaudinn's fluid and stained with Heidenhain's iron-hematoxylin. Measurements and figures were made from the prepared material. The length measured was that from the anterior end of the body to the distal tip of the axostyle; the width was taken at the widest point. Enlarged camera lucida drawings were used for the figures to insure correctness of proportion.

The three species of sandpipers, collected at Ruthven, Iowa, harbored in their intestines specimens of Trichomonas which were morphologically similar in each host. The slight differences in size may be seen below in table 1.

TABLE 1. *Comparative sizes of Trichomonas from three species of sandpipers*

	Length	Width
Least sandpiper		
Mean	$7.31\ \mu$	$3.14\ \mu$
Range	$5.0\text{-}9.5\ \mu$	$2.0\text{-}4.0\ \mu$
Pectoral sandpiper		
Mean	$6.98\ \mu$	$3.21\ \mu$
Range	$5.5\text{-}9.0\ \mu$	$2.5\text{-}4.0\ \mu$
Semipalmated sandpiper		
Mean	$8.11\ \mu$	$3.17\ \mu$
Range	$6.0\text{-}10.0\ \mu$	$2.5\text{-}4.0\ \mu$

To arrive at definite conclusions concerning the specific status of the trichomonads from these three hosts would be practically impossible. If the writers were to follow the procedure, in vogue among many contem-

porary parasitologists, of naming forms living in different hosts as separate species, they might consider three species of Trichomonas to be present; but, if they followed morphological separation rather than host separation, they might consider only one species to be present. They are inclined toward the latter concept because, (1) the morphology of the flagellates from the three birds is apparently identical, (2) the birds are closely related, and (3) the slight differences in measurements are within the range of one species. The name *Trichomonas* (*Trichomonas*) *pisobiae* is proposed for this species.

Trichomonas (*Trichomonas*) *pisobiae* n. sp.

(Plate I, fig. 1-3)

This flagellate was present in large numbers in the intestines of the least sandpiper, pectoral sandpiper, and the semipalmated sandpiper. The body is curved-pyriform and somewhat bulged in the nuclear region. Cor-

TABLE 2. *Correlation table of the length and width of 100 specimens of Trichomonas pisobiae n. sp. from the least sandpiper*

Width in microns	Length in microns										
	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	Total
2							2				2
2.5				1	2	1		1			5
3	1	1	5	5	18	15	7	1	5	1	59
3.5			1	8	4	7	7	2	1		30
4					4						4
Total	1	1	6	14	28	23	16	4	6	1	100

	Length	Width
Mean	7.31 μ	3.14 μ
Range	5.0-9.5 μ	2.0-4.0 μ

TABLE 3. *Correlation table of the length and width of 100 specimens of Trichomonas pisobiae n. sp. from the pectoral sandpiper*

Width in microns	Length in microns								
	5.5	6	6.5	7	7.5	8	8.5	9	Total
2.5	6	1	2	3					12
3	6	9	3	9	7	8		1	43
3.5		6	2	11	8	6	2	1	36
4		1	1		2	2	1	2	9
Total	12	17	8	23	17	16	3	4	100

	Length	Width
Mean	6.98 μ	3.21 μ
Range	5.5-9.0 μ	2.5-4.0 μ

relation tables are given for each of the three hosts since there is some difference in the measurements of the parasites from the three birds (tables 2, 3 and 4).

A narrow crescentic cytostome is present in many specimens, but it is difficult to demonstrate. There are four free, very slender, anterior flagella, 11.0-16.0 μ long. The undulating membrane is narrow and not easily seen in stained material. The marginal flagellum extends free 4.0-6.0 μ at the posterior end.

The blepharoplast appears as a single, large, siderophilous granule at the extreme anterior end of the body. The chromatic basal rod or costa is long, but narrow and not strongly staining. The axostyle, which is difficult to trace far into the cytoplasm, is slender, hyaline, and pointed. It projects 1.0-2.0 μ from the posterior end of the body.

TABLE 4. *Correlation table of the length and width of 100 specimens of Trichomonas pisobiae n. sp. from the semipalmated sandpiper*

Width in microns	Length in microns									
	6	6.5	7	7.5	8	8.5	9	9.5	10	Total
2.5	1	1	3	2	1	2	3			13
3	2	2	6	8	12	5	4	4	1	44
3.5	1	1		7	9	4	9	5	3	39
4		1				2	1			4
Total	4	5	9	17	22	13	17	9	4	100

	Length	Width
Mean	8.11 μ	3.17 μ
Range	6.0-10.0 μ	2.5-4.0 μ

The nucleus is prominent and large, measuring 1.5-2.0 μ in diameter. At times it is so large that it appears to distend the body in the nuclear region. The nuclear membrane is thick and strongly staining. Only occasionally are chromophilic granules observed in the nucleus of this species, and then they are somewhat indistinct.

The cytoplasm is not vacuolated and is even staining. No food material was observed.

Trichomonas (*Tritrichomonas*) *chordeilis* n. sp.

(Plate 1, fig. 6-7)

A moderately large Trichomonas was found to be abundant in the intestine of a night-hawk, *Chordeiles minor* (Forster), collected at Ruthven, Iowa. The body is broadly spindle-shaped with a range in length of 7.0-12.5 μ and in width of 4.0-6.5 μ. The mean size for 100 individuals was 8.64 μ in length and 5.04 μ in width. These data may be further studied in table 5.

The cytostome is long, narrow, and crescentic. There are three free anterior flagella 10.0-12.0 μ long. A fourth flagellum margins the narrow undulating membrane and extends free 4.0-6.0 μ from the posterior end of the body.

The blepharoplast is a large siderophilous granule situated at the extreme anterior end of the body. The costa is indistinct, more often appearing as a row of small granules that follows the base of the undulating membrane for about one-half the length of the body. The axostyle stains feebly and is difficult to trace far into the cytoplasm. It is slender and hyaline, tapering to a long point and protruding 2.0-4.0 μ from the posterior end of the body. In a few cases the axostyle was seen in the body as a large hyaline rod whose diameter decreased abruptly before projecting from the body.

The prominent nucleus measures 2.5-4.0 μ in diameter and varies from ovoidal to ellipsoidal in shape. The nuclear wall is thick and stains well. A small karyosome is frequently present, and is usually eccentric in position. It is immediately surrounded by a narrow, clear halo. A number of small round siderophilous granules are scattered around the nucleus, occasionally arranged in a definite linear series on the right of the nucleus and extending back about one-half the length of the body (fig. 7).

The cytoplasm is rather granular and conspicuously vacuolated. No food material was observed in the vacuoles.

TABLE 5.   *Correlation table of the length and width of 100 specimens of Trichomonas chordeilis n. sp. from the night-hawk*

Width in microns	Length in microns												Total
	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	
4	2	5	1	3	2	1	2						16
4.5	4	1	2	2	2	2	1			1		1	16
5	3	6	5	5	5	4	2	1			1		32
5.5	1	2	5	2	4	3		1	1				19
6		1	3	2	2	4	1	1					14
6.5			1				2						3
Total	10	15	17	14	15	14	8	3	1	1	1	1	100

	Length	Width
Mean	8.64 μ	5.04 μ
Range	7.0-12.5 μ	4.0-6.5 μ

Trichomonas (Trichomonas) iowensis n. sp.

(Plate I, fig. 4-5)

A heavy infestation of this flagellate was observed in the intestine of a night-hawk, *Chordeiles minor* (Forster), collected at Ruthven, Iowa. Morphologically it is very similar to *T. phasiani* Travis (1930), differing slightly in size and in the presence of chromatin granules dorsal to the costa. The body shape varies from curved pyriform to broadly ovoidal. The mean size for 100 specimens was 7.36 x 3.36 μ, with a range in width of 2.5-4.0 μ and in length of 5.5-9.5 μ. Measurements for 100 specimens may be seen in table 6.

The crescentic cytostome is rather conspicuous. There are four anterior free flagella 8.0-10.0 μ long. A fifth flagellum passes along the outer edge

of the moderately high undulating membrane and extends free a distance of 4.0-5.0 μ at the posterior end.

The blepharoplast is a large granule placed at the anterior end of the body. The costa is prominent. Between the costa and the dorsal side of the body is a series of granules, similar to the granules in *T. gallinarum* Martin and Robertson (1911). The walls of the axostyle stain feebly, making this structure rather inconspicuous. The distal end of the axostyle is pointed and projects slightly.

The nucleus is prominent and ellipsoidal, measuring 1.5 x 2.5 μ. An eccentric karyosome is present, surrounded by a clear halo. The remainder of the nucleus is filled with small siderophilous granules.

The cytoplasm is slightly vacuolated but no food material was observed in the vacuoles.

TABLE 6. *Correlation table for the length and width of 100 specimens of Trichomonas iowensis n. sp. from the night-hawk*

Width in microns	Length in microns									
	5.5	6	6.5	7	7.5	8	8.5	9	9.5	Total
2.5	1	1		6	1	4				13
3	1	2	2	7	4	2	1	1		20
3.5	2	5	3	12	10	9	3	4	1	49
4				7	4	5		1	1	18
Total	4	8	5	32	19	20	4	6	2	100

	Length	Width
Mean	7.36 μ	3.36 μ
Range	5.5-9.5 μ	2.5-4.0 μ

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EXPLANATION OF PLATE I

x 4000

Fig. 1-3   *Trichomonas pisobiae* n. sp.

Fig. 4-5   *Trichomonas iowensis* n. sp.

Fig. 6-7   *Trichomonas chordeilis* n. sp.

PLATE I

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